REVIEW OF THE SAGEBRUSH BIOME: STATE OF KNOWLEDGE, OF RESEARCH NEEDS AND FUEL DYNAMICS WITHIN THE SAGEBRUSH BIOME FOR BUILDING AND VALIDATING ECOLOGICAL MODELS

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A REVIEW OF THE SAGEBRUSH BIOME: STATE OF KNOWLEDGE, OF RESEARCH NEEDS AND FUEL DYNAMICS WITHIN THE SAGEBRUSH BIOME FOR BUILDING AND VALIDATING ECOLOGICAL MODELS

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PREFACE

The purpose of this Research Joint Venture Agreement[1] was to develop an extensive review of the literature on vegetation and fuel dynamics within the sagebrush biome and to document existing models that predict rangeland vegetation succession or productivity. We begin our review by describing how the sagebrush biome has been described ecologically and the importance of the biome related to its extent and values. Threats to the sagebrush biome, including invasive plants, changing fire regimes, encroachment of forests and woodlands, climate change and agriculture conversion are reviewed in the section "*Major Threats to the Sagebrush Biome*". The major sagebrush species including their environments, growth habits (autecological aspects), fire ecology, and management aspects are reviewed in the section "*Sagebrush Species: A Review of Autecological and Synecological Information*". This information is mostly from the Fire Effect Information System or FEIS (http://www.fs.fed.us/database/feis/index.html) and was considered important as basic background information for individuals with experience in forest modeling and the Forest Vegetation Simulator (FVS) that were assigned to determine using information in this report if data was available for developing a Rangeland Vegetation Simulator (RVS) similar in characteristics to the FVS. Although we attempted to examine all literature dealing with synecological and autecological aspects of sagebrush species and the sagebrush biome, we stress the Great Basin and Columbia Basin geographic areas.

Following these sections, we review many of the ecological models used in rangeland ecosystems in the western U.S. and postulate on some of their strength and weaknesses. These included stochastic, mechanistic, and GIS models as well as fuel and fire models. We stress that there have been many ecological models developed for use in rangeland ecosystems and we did not attempt to examine every model that has been developed to examine rangeland processes.

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[1] Agreement No. 04-JV-11222088-224: Status of Knowledge of Research Needs and Fuel Dynamics within the Sagebrush Biome for Building and Validating Ecological Models.

However, we do believe that we reviewed all the relevant and currently utilized rangeland models. In our review of models we were particularly interested in modeling succession, including exotic plant invasion, and the ability of models "grow" plant communities and changes associated with disturbance including grazing, fire, drought, etc. Because we considered the FVS mechanistic model as the type of model needed (mechanistic model developed for decision support initially at he plot basis) our assessment and needs section stresses the need for very specific plot information.

We end with a brief summary and recommendations on the development of a rangeland simulation model for the sagebrush biome. This section is predominately associated with what we see as a need for the development of a basic decision support system to aid land managers, especially in project planning, with better ways to assess and analyze information and thus understanding these systems. It is relatively easy to suggest that because of the complexity of these ecosystems that modeling will be unlikely to provide all of the answers necessary; however, without a more concerted effort land managers will continue to struggle with even the most basic decisions in regard to management of sagebrush communities.

The information in this report, as an earlier draft, was presented to Mr. Duncan Lutes for his determination of the applicability of the information for development of a "Rangeland Vegetation Simulator" or RVS, similar to the Forest Vegetation Simulator (FVS). We included a number of scanned figures and images to provide this information for the review. At this time this report is not publishable because we would still need to obtain copy right release forms from the appropriate publishers. As such, this report in current form is considered a draft document.

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INTRODUCTION

The sagebrush (*Artemisia*)-grasslands comprise the largest rangeland vegetation biome in western North America. Sagebrush taxa occur on 109 million ha (Beetle 1960; McArthur and Plummer 1978 from Wambolt 2001) and sagebrush vegetation types in the western U.S. are estimated to cover 58 million ha (Branson and others 1967) to 63 million ha (West 1983 a and b). Sagebrush cover types vary associated with differences in climate, soils, and past disturbances. However, this expansive ecosystem is far from intact. Years of livestock grazing, altered fire regimes, exotic species invasion, conversion to agriculture, conversion to urban use, and resource development, among other things, have dramatically altered and reduced these ecosystems by millions of hectares (Hann and others 1997, West 1999). Furthermore, almost 20 percent of all plants and animals found within sagebrush and other semi-arid and arid environments may be at risk of extirpation (Center for Science, Economics and Environment 2002). The combination of these environmental and social pressures on the sagebrush biome led Noss and others (1995) to classify the sagebrush ecosystems as one of the most endangered in the United States.

Continued decline of greater sage-grouse populations and habitat (Connelly and Braun 1997) has drawn considerable attention to the condition of the sagebrush ecosystem. As a result projects such as SAGEMAP (USGS 2004) and the *Regional Assessment of Habitats for Species of Conservation Concern in the Sagebrush Ecosystem* (Wisdom and others 2003) are being implemented to better capture sagebrush distribution and site conditions. These projects aim to map sagebrush habitats and assess habitat conditions to identify threats to various species of concern. While updating our knowledge of the extent and condition of sagebrush ecosystems is critical, we must also continue to advance our understanding of sagebrush ecosystem function

and disturbance response. For example, cheatgrass (*Bromus tectorum*) and other invasive species have replaced native perennials as the dominant understory cover in sagebrush types following intensive grazing and large wildfires (Billings 1994, Hann and others 1997). As a result, fire regimes have changed in sagebrush types, in some cases resulting in the complete conversion of the site to an annual grass type (Monsen and Kitchen 1994). While we have documented this process, the question becomes, "Do we have enough knowledge of this process to predict or model it accurately?" Several decision support systems (DSS) have attempted to capture sagebrush ecosystems at various levels of complexity (Hemstrom and others 2002, Jones 2005). In an effort to better understand the knowledge base regarding sagebrush ecosystems and associated modeling efforts an extensive literature review is needed. A review of the ecological and DSS literature will identify knowledge gaps, while confirming model logic and highlighting system strengths, and the limitations.

We reviewed literature pertaining to sagebrush ecosystems to provide a comprehensive knowledge summary of these communities, which in turn, will identify further research needs. We attempted to review information of sagebrush shrub types throughout the western U.S., but concentrated on the "center" of sagebrush dominated ecosystems of the Great Basin and Intermountain region. We also reviewed DSS platforms that capture sagebrush communities, to identify the logic and limitations of these models. Specifically we were tasked with investigating sagebrush species and communities found in the Great Basin, however relevant information from studies in other geographic areas is included.

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ECOLOGICAL REVIEW

Sagebrush Biome Overview

Sagebrush vegetation types occur throughout the western U.S. and into areas of southern Canada. These types vary associated with differences in climate, soils, and past disturbances. Reviews of the Great Basin and Colorado Plateau Sagebrush Semi-desert ecosystems often incorporate the more mesic Intermountain Sagebrush Steppe (Anonymous 1979); however, West (1983a,b) makes a distinction between the two ecosystems based on their response to perturbation. He notes that arid systems often take longer to recover following grazing and fire, and damage to these areas is not as easily reversed. There are no clear boundaries in nature; however, differences in precipitation and soil development often create a continuum from the driest sagebrush dominated sites to more mesic sites with a much larger herbaceous component. The information presented herein will apply to both ecosystem types in an effort to provide context and depth to the discussion. We believe that for the most part that the values and also the problems and concerns are similar for sagebrush types within the Great Basin and the Intermountain sagebrush grassland types. Appendix A presents the species discussed in this report and general site characteristics of these species.

Great Basin—Colorado Plateau Sagebrush Semi-desert

The Great Basin—Colorado Plateau Sagebrush Semi-desert ecosystem occurs in areas dominated by woody sagebrushes (*Artemisia*) even when pristine or near pristine conditions exists (West 1983a). The sagebrush semi-desert type is located throughout Nevada, Utah, Arizona, Colorado, California, and New Mexico (West 1983a) (Appendix B). Wisdom and others (2003) found sagebrush cover types occupied 8.3 million ha of the Great Basin, second in

sagebrush cover to the Columbia Plateau Ecoregion. This type is found south of the sagebrush steppes and north of the creosotebush and blackbrush types. It is elevationally situated between the salt-desert shrublands and xeric conifer woodlands, and pinyon-juniper woodlands (West and others 1978). A semi-arid temperate continental climate influences most of this area. Temperature ranges are extreme and precipitation ranges from 6.2 to 16.5 inches annually (West 1983a). This type occupies broad alluvial valleys at elevations from 3,900 to 5,900 feet. Soils range from Aridisols toward Mollisols and Alfisols. Major sagebrush species do not tolerate soils with salinity conductivities greater than 18 mS cm^{-1} (West 1983a).

Various sagebrush species dominate these semi-desert communities (table 1), even when degraded. These dominant species occupy specific environmental niches throughout the Great Basin and Colorado Plateau as a result of elevation and moisture gradients (Appendix C). Although species rarely exceed 3.3 feet in height, sagebrush comprises approximately 70 percent of the relative cover and 90 percent of the biomass with the absolute cover of higher plants from 10 to 40 percent (West 1979, 1983). Bunchgrasses and perennial forbs are the common understory species on undisturbed sites with cheat grass (*Bromus tectorum*) and less commonly medusahead (*Taeniatherum caput-medusae*) invading disturbed communities (Billings 1994, Hann and others 1997, Young and Evans 1971, Connelly and others 2004).

Table 1—Dominant sagebrush species (*Artemisia* spp.) of the Great Basin and Colorado Plateau Semi-desert.

Great Basin	Colorado Plateau
Wyoming big sagebrush-*A. tridentata* ssp. *Wyomingensis*	Wyoming big sagebrush-*A. tridentata* ssp. *wyomingensis*
Mountain big sagebrush-*A. tridentata* ssp. *vaseyana*	Mountain big sagebrush-*A. tridentata* ssp. *vaseyana*
Basin big sagebrush-*A. tridentata* ssp. *tridentata*	Basin big sagebrush-*A. tridentata* ssp. *tridentata*
Black sagebrush-*A. nova*	Black sagebrush-*A. nova*
Low sagebrush-*A. arbuscula*	Bigelow sagebrush-*A. bigelovii*
Alkali sagebrush-*Artemisia arbuscula* ssp. *longiloba*	
Bud sagebrush-*Picrothamnus desertorum*	
Silver sagebrush-*A. cana*[1]	
Threetip sagebrush-*A. tripartita*[1]	

Source: West 1983a.
[1] Wisdom and others 2003.

A high proportion of the phytomass in these systems is in the soil (West 1972 as cited by West 1983a). This is likely the result of a cold, dry climate, making the soil a more favorable location for biological activity (West 1983a). Above ground standing crop phytomass varies from 1,786 to 10,716 lb/ac (Shepard 1977 as cited by West 1983a). Litter standing crops are approximately half of the total above ground phytomass, and—where measured—below ground phytomass is of a magnitude similar to that of above ground phytomass. Two sources of variation in these estimates are successional status and stand age. In general, degraded sites will have more phytomass due to higher brush proportions. Annual net primary productivity varies between 447 and 1,340 lb/ac depending on the site, successional status, stand age, and climatic conditions (West 1983a).

Historically, it appears fire was not a frequent or pervasive ecological process in this ecosystem type. If it were, one would have expected early observers to document larger proportions of the flora dominated by root-sprouting shrubs (West 1983a). Now however, as a result of livestock grazing and large wildfires, cheatgrass (*Bromus tectorum*) and other invasive species have replaced native perennials as the dominant understory cover (Billings 1994, Hann and others 1997). As a result of changing fire regimes, fire plays a much larger role in this ecosystem.

Intermountain Sagebrush Steppe

The Intermountain Sagebrush Steppe is found in areas exhibiting a codominance of woody sagebrush species and bunchgrasses under semi-arid, pristine conditions (West 1983b). Sagebrush species are favored by edaphic conditions that promote aridity, the presence of heavy livestock grazing during the growing season, and fire prevention. Located throughout

northwestern Nevada, eastern Oregon, and potions of southern Washington, the Intermountain Sagebrush Steppe extends through south-central Idaho and into much of Wyoming and portions of southwestern Montana (Appendix D). Elevations range from less than 500 feet along the Columbia River to over 7,000 feet in the Wyoming Basin. This ecosystem is the largest of North America's temperate semi-deserts and, in contrast to the Great Basin—Colorado Plateau Sagebrush Semi-desert, is more diverse, productive, and resilient (West 1983b).

The semi-arid temperate and continental climates have a lack of clouds and water vapor during the summer months that create a climate of intense diurnal heating and cooling. Average annual precipitation is 9.68 inches with 20 percent coefficient of variation and the ratio of snow to rain is 10:1. However, much of the moisture in snow is lost as vapor through sublimation. Mast and others (1971 as cited by West 1983b) hypothesizes this effect results in more arid conditions than are expected from the precipitation data.

These dry sites support moderate floristic diversity (West 1979). In Washington, Daubenmire (1975a as cited by West 1983b) found an average of 20 species on 1,000 m^2 relict sites. Total species cover on relict sites varies greatly, from 80 to 200 percent depending on the site and successional stage. Shrubs commonly cover from 10 to 80 percent of the area; while herbaceous canopy cover varies from 0 to 100 percent. Despite highly variable canopy cover across sites, vertical and horizontal structure is very similar. The shrub layer is from 1.6 to 3.3 feet tall and the herbaceous layer is from 1.0 to 1.3 feet tall during the growing season. Aboveground biomass ranges from approximately 700 to 2,200 lb/ac (West 1983b).

A number of different sagebrush species are found throughout this ecosystem. These species—which include big sagebrush (*Artemisia tridentata*) and major subspecies, low sagebrush (*A. arbuscula*), and silver sagebrush (*A. cana*), among others—aggregate into

particular niches (West 1983b). Soil temperature and moisture conditions are some of the environmental gradients that influence species range (Appendix E).

Herbaceous species also segregate along environmental gradients. Bluebunch wheatgrass (*Pseudoroegneria spicata*) is the most widespread and important understory species in the region. Idaho fescue (*Festuca idahoensis*) and other members of the genus are frequently found in northwestern communities, as well as the highest elevations and latitudes elsewhere. Along the eastern portion of the ecosystem, western wheatgrass (*Pascopyrum smithii*) and other sod forming grasses become increasingly important, whereas members of the genus *Stipa* are found throughout the southwestern boundary of the type (West 1983b).

Major Threats to the Sagebrush Biome

Bunting and others (2002) found five major sources of alteration in sagebrush communities of the interior Columbia basin: 1) introduction of invasive species; 2) livestock grazing; 3) modified fire regimes; 4) climatic change; and 5) activities related to human presence (i.e., urbanization, agriculture, road development, etc.). All of these disturbance factors are interrelated and are magnified by climate change. For instance, invasive annual grasses affect fire regimes and species competition by increasing fire frequencies which shifts the competitive advantage to invasive annuals (Pellant 1990). Due to the interaction between these factors and individual species interactions it is impossible to isolate a primary cause of vegetation alteration.

To further classify community alteration in the Interior Columbia Basin, Bunting and others (2002) identified 7 tall sagebrush potential vegetation types[2] (PVT) and 5 dwarf sagebrush PVT that have been altered (table 2). The most prevalent factors affecting these PVT are past livestock grazing, invasive species, and changes in fire regime. Climate change is thought to be an important factor also; however it is difficult to quantify its influences. On private lands, agricultural development is an important factor. Appendix F lists the 12 PVT, associated cover types, environmental setting, stages of alteration, and fire characteristics.

Table 2—Sagebrush potential vegetation types and their primary disturbance factors in the Interior Columbia Basin.

Species	Primary disturbance factor
	Tall Sagebrush Potential Vegetation Types
Wyoming big sagebrush-warm	Past livestock grazing, invasive species, increased fire occurrence.
Wyoming big sagebrush-cool	Past livestock grazing, invasive species, increased fire occurrence.
Basin big sagebrush	Agricultural development, Past livestock grazing, invasive species, increased fire occurrence.
Mountain big sagebrush-mesic east	Decreased fire occurrence, invasive species.
Mountain big sagebrush-mesic east with conifers	Decreased fire occurrence, invasive species.
Mountain big sagebrush-mesic west	Decreased fire occurrence, past livestock grazing.
Mountain big sagebrush-mesic west with conifers	Decreased fire occurrence, past livestock grazing.
	Dwarf Sagebrush Potential Vegetation Types
Salt desert shrub	Past livestock grazing, invasive species, increased fire occurrence.
Threetip sagebrush	Past livestock grazing, invasive species, increased fire occurrence.
Low sagebrush-xeric	Past livestock grazing, invasive species.
Low sagebrush-mesic	Past livestock grazing, invasive species.
Low sagebrush-mesic with juniper	Decreased fire occurrence

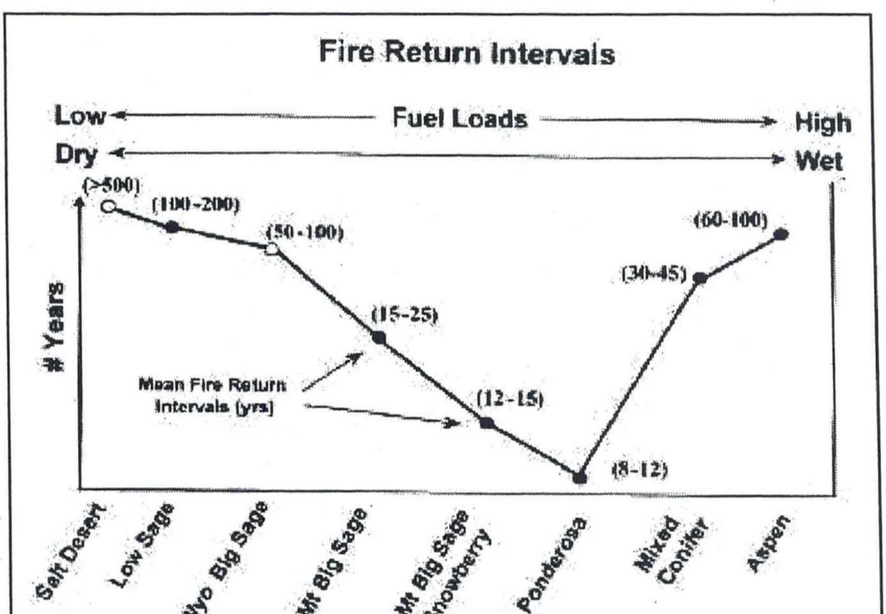
Source: Bunting and others 2002.

The various subspecies of big sagebrush exhibit different primary factors of site alteration. Introduction of invasive annual grasses alters the fire regimes in Wyoming big

[2] A "potential vegetation type" is the representation of the biophysical properties of a portion of land that is described by the successional convergence to a homogenous vegetation community (Bunting and others 2002).

sagebrush communities (table 2). Annual grasses such as cheatgrass and medusahead produce abundant, highly flammable fuel resulting in frequent fire, enhanced annual grass domination, and near elimination of sagebrush species (Pellant 1990). The major disturbance factor in basin big sagebrush communities is agricultural development (table 3) (Bunting and others 2002). Due to the productive deep soils, and moderate slopes the majority of these sites have been converted to agricultural uses (Hironaka and others 1983). Mountain big sagebrush communities are being converted to woodland and forest types due primarily to a decrease in fire occurrence (table 2 and figure 1). Fire occurrence has decreased in these communities as a result of fire suppression and removal of fine fuels by grazing. The lack of fire has allowed for more continuous forest canopy development and expansion into sagebrush communities (Arno and Gruell 1983). Fire is considered to be the most important factor in maintaining shrub steppe communities and open pinyon and juniper savannas before Eurasian settlement (West 1999 as cited by Miller and Tausch 2000).

Figure 1—Estimated (open circle) and documented (closed circle) fire mean return intervals for major cover types found in the Great Basin.



Source: Miller and Tausch 2000.

Dwarf sagebrush communities are primarily affected by past livestock grazing and subsequent invasive annual grass understory conversion (table 2) (Bunting 2002). In the early 20th century large areas were impacted by livestock and feral horse grazing. Low sagebrush sites were traditionally used by sheep and more recently by cattle for winter range (Blaisdell and Holmgren 1984). With increased grazing pressure, species such as winterfat (*Krascheninnikovia lanata*) decrease (Blaisdell and Holmgren 1984) cheatgrass increases as the shrub cover decreases. While these sites normally do not support fire due to sparse species distribution and low site productivity (Tisdale and Hironaka 1981, Blaisdell and others 1982), the may produce enough biomass to support wildfire during years of above-average precipitation if cheatgrass is present (Pellant and Reichert 1984). More frequent fires favor the establishment of annual grasses.

Mesic low sagebrush sites adjacent to pinyon-juniper woodlands historically had less than 5 percent juniper cover (Bunting and others 2002). Infrequent fire in these types maintained this savannah-like structure. Active fire suppression and removal of fine fuels due to grazing have sufficiently decreased fire occurrence to allow for juniper establishment and growth over the last 150 years (Miller and Rose 1999, Miller and Wigand 1994). Low fine fuel loads make prescribed fire difficult to execute and is seldom used in this PVT (Blaisdell and others 1982).

Additional sagebrush die-off may be the result of single factors or combinations of drought, excessive moisture, increased soil salinity, parasites, disease, insects such as the sagebrush moth (*Aroga websteri* Clarke) affecting both Wyoming big sagebrush (Passey and Hugie 1962) and low sagebrush communities (Furniss and Barr 1975), and grazing pressure (McArthur and others 1990). Changes in climate (to be discussed in a later section) may also interact with other factors to stress a number of the sagebrush types.

Invasive Plants

There is little doubt that the introduction of cheatgrass and other exotic annuals have had dramatic impacts on the sagebrush biome. Peters and Bunting (1994) have suggested the introduction of exotic annual grasses including cheatgrass into the Snake River Plain in Idaho may have been the most important event in the natural history of that region since the last glacial period. Billings (1994) raised the concern of catastrophic ecosystem change for the western Great Basin as function of cheatgrass. Goodrich and Gale (1999) state that cheatgrass can be expected to be a major ecologic force within its ecological amplitude, which includes some cold desert shrub, many sagebrush communities, pinyon-juniper, and mountain brush communities. Cheatgrass and medusahead (winter annuals) are the most problematic herbaceous species in the sagebrush biome (Connelly and others 2004); although, other exotic invaders maybe locally abundand. Cheatgrass and medusahead tend to be more influential in the dry Intermountain West as opposed to the Rocky Mountain States of Montana, Wyoming, and Colorado. Wyoming big sagebrush sites are particularly susceptible to cheatgrass invasion, although medusahead is now filling a similar niche in mesic communities with heavier clay soils. As a result, low sagebrush and mountain big sagebrush communities with the presence of a clay soil horizon are now being altered in addition to sites traditionally altered by cheatgrass (Connelly and others 2004).

A Bureau of Land Management (BLM) 1991 study estimates invasive annual grasses now occpy (estimated >10% composition based on biomass) approximately 70,000 km^2 of public land throughout Washington, Oregon, Idaho, Nevada, and Utah (from Connelly and others 2004). Annual grasses, primarily cheatgrass dominates about 25 million acres of the Great Basin, roughly one-third of the land in the area, and cheatgrass invades 4,000 acres a day

(http://www.fire.blm.gov/gbri/whatis.html). Cheatgrass is especially adept at taking over disturbed areas, such as recently burned land becaude of its prolific seed production with a single acre containing hundreds of thousands of the plants with each plant capable of producing hundreds of seeds. Cheatgrass is a volatile fuel that carries fire quickly, and is the primary reason behind the Great Basin's downward ecological spiral (http://www.fire.blm.gov/gbri/whatis.html).

Booth and others (2003) state that the most successful exotic invaders are those that restructure their environment to favor their long-term persistence; thus, ultimately resetting the course of community or plant succession. In the Great Basin invasive species, especially cheatgrass, have significant effects on ecosystem function by altering fire regimes, nutrient loss, altered local microclimate, and prevention of succession (d'Antonio and Vitousek 1992), and is consistently referred to as one of the main challenges to maintenance of healthy sagebrush communities. Table 3 summarizes environmental variables associated with cheatgrass, exotic grasses and native grasses across the sagebrush biome. The table illustrates the similarity of conditions where cheatgrass, exotic grasses and native grasses were found.

Furthermore, cheatgrass autecology (i.e., early germination and drying) results in increased risk of wildfire that eliminates sagebrush species (Billings 1994). Booth and others (2003) believe that the climatic regime of the Great Basin has proved to be ideal for cheatgrass. Autumn rains trigger germination, and root growth continues at low temperatures, so that the plant is ready to take advantage in spring of what is essentially a high-resource environment, at least for a short time (Booth and others 2003). The impact of cheatgrass and other invaders are thought to have reduced the Great Basin's ecological resiliency and as such has greatly increased the need for restoration (http://www.fire.blm.gov/gbri/whatis.html). Pellant (1990, 1996) stressed the difficulty of exotic inavaders as have others; however, Booth and others (2003)

found that *Elymus elymoides* suppressed cheatgrass in Curlew Valley, Utah which may also facilitate sagebrush as sagebrush only recruits in cheatgrass free areas. Others (Young and others 1995) have reported that reductions in inorganic nitrogen availability may inhibit annual invaders.

Table 3—Summary statistics for environmental variables associated with cheatgrass, combined species of exotic grasses including cheatgrass, and native grasses across the sagebrush biome[1].

Region	Functional groups	N	Elevation (m)	Slope	Precipitation	Depth to rock (cm)	Soil pH	Soil salinity	Available water capacity (cm)
Colorado Plateau	Cheatgrass	78	1551	4	28	88	6.3	1.12	11
	Exotic grasses	92	1645	5	31	88	6.3	1.12	11
	Native grasses	198	1660	11	29	87	6.3	1.21	10
Columbia Basin	Cheatgrass	495	655	13	29	93	6.2	0.34	13
	Exotic grasses	577	667	13	30	95	6.2	0.32	13
	Native grasses	744	761	13	31	90	6.1	0.28	12
Northern Great Basin	Cheatgrass	705	1,456	10	30	111	6.4	2.52	11
	Exotic grasses	777	1,462	9	30	110	6.3	2.39	11
	Native grasses	923	1,591	8	35	99	5.8	1.45	10
Snake River	Cheatgrass	887	1,379	10	34	106	6.4	1.55	13
	Exotic grasses	1,502	1,504	10	38	111	6.5	1.46	13
	Native grasses	3,795	1,787	13	45	111	6.3	1.15	12
Southern Great Basin	Cheatgrass	2,383	1,655	10	28	113	6.8	2.86	10
	Exotic grasses	3,057	1,744	11	32	113	6.7	2.59	11
	Native grasses	6,560	1,956	13	37	110	6.6	2.12	11
Wyoming Basin	Cheatgrass	172	1,843	9	27	88	6.6	1.89	11
	Exotic	298	1,940	10	39	100	6.7	1.43	12

grasses								
Native grasses	1,099	2,093	12	44	103	6.9	1.23	13

Source: Connelly and others 2004.

[1] Percent cover was not reported due to differences in sampling techniques.

Wisdom and others (2003) used a rule-based model to develop a risk categorization of the Great Basin and Nevada to cheatgrass invasion (also see section on GIS models). They found that about 80% of the area is "susceptible to displacement by cheatgrass". Wyoming-basin big sagebrush and salt desert scrub cover types were at the greatest risk of displacement; whereas, mountain big sagebrush were generally at lower risk.

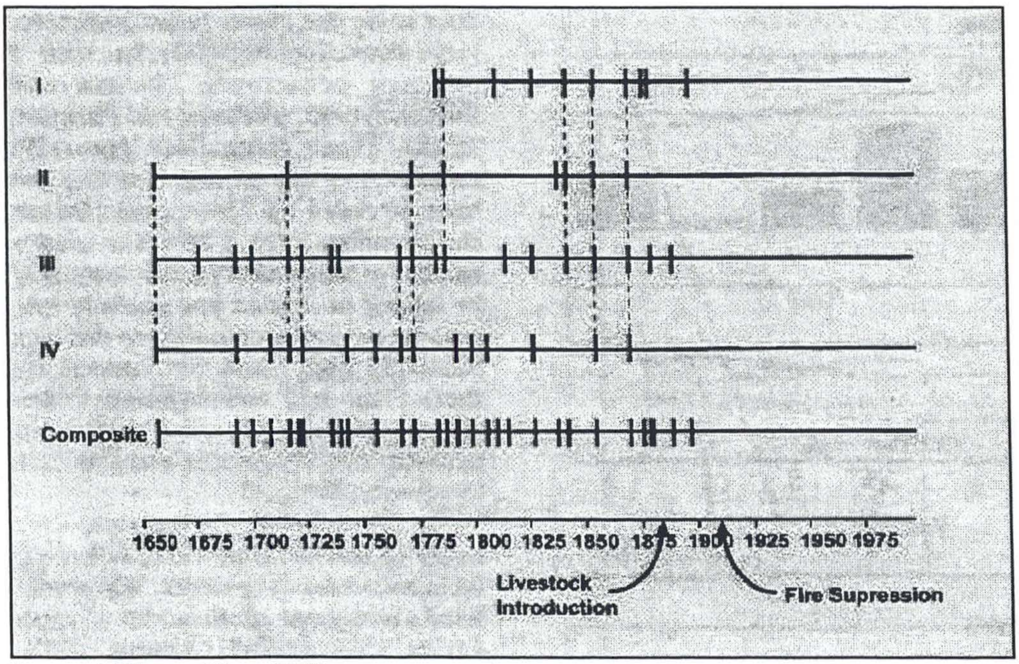
Changing Fire Regime

Throughout the Great Basin and Interior Columbia Basin fire regimes have been altered in sagebrush ecosystems resulting in greater fire severity, decreased fire frequency, and encroachement of woody species and in some cases exotic annuals (Miller and Rose 1995, 1999, Miller and Tausch 2000, Bunting and others 2002). These changes have inturn altered the successional response of many of these ecosystems.

In southcentral Oregon Miller and Rose (1999) sampled fire scarred ponderosa pine spanning from 1601 to 1996 growing adjacent to mountain big sagebrush communities. In addition, burned wood samples were used to categories fire events in low sagebrush communities. Results show mean fire intervals in mountain big sagebrush communities prior to 1871 ranged from 12 to 15 years with a 100 percent probability fire would occur within 45 years (figure 2). In these communities a minimum of 45 years is required for western juniper to reach 3 m in height. Western juniper less than 3 m tall are highly seceptible to fire damage, thus a fire return interval of 40 to 50 years would inhibit western juniper encroachment into this communities (Burkhardt and Tisdale 1976, Miller and Rose 1999). In low sagebrush communities tree densities have increased significantly (Miller and Rose 1995, 1999, Young and

Evans 1981). Mean fire intervals in these communities are considerabily longer due to lower site productivity and fuel accumulations. Miller and Rose (1999) report a mean fire interval of approximately 100 years while Young and Evans (1981) reported up to 90 years between fire events. Climate played an import role in initiating large fires. Large fires were usually preceded by at least 1 year of above average tree growth (Miller and Rose 1999).

Figure 2—Master fire chronology for mountain big sagebrush steppe community in the upper Chewaucan River basin. Fire history extends from 1601 to 1996. Horizontal lines represent a sample composite for each collection site with the bottom line being a composite for all fire scar samples. Vertical lines designate a fire occurrence. Dashed lines connect collection sites where fires occurred across 2 or more sites in the same year.



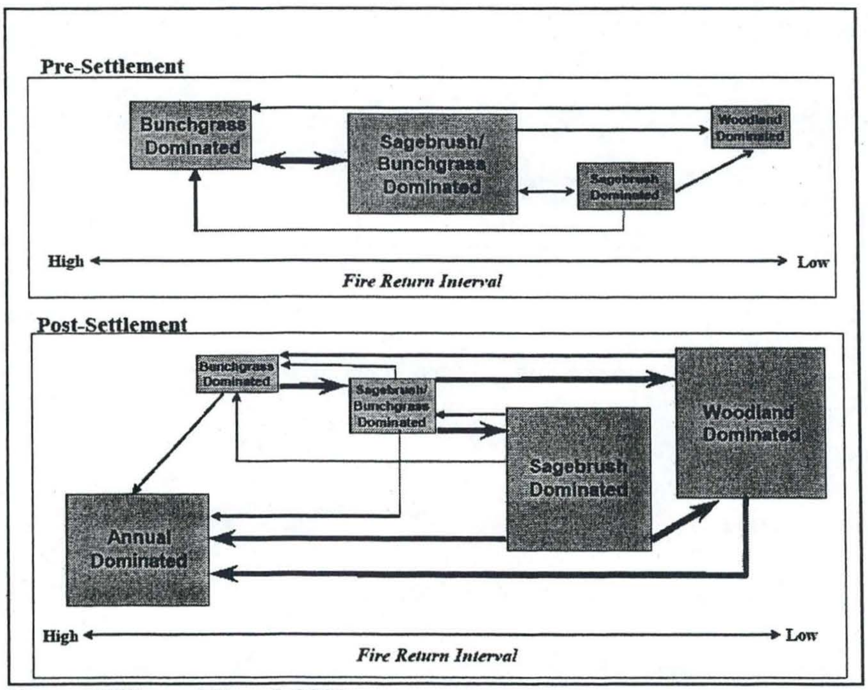
Source: Miller and Rose 1999.

In areas were exotic annual grasses such as cheatgrass and medusahead displace native understory vegetation fire return intervals have been radically altered (figure 3a) (Bunting and others 1987, Hironaka 1991, Shaw and Monsen 1990, McArthur and others 1998). Cheatgrass is common in frequently disturbed sites (Evenden 1989) and is found as the dominant understory species in many communities throughout southern Idaho, northern Nevada, and eastern Oregon. Annual cheatgrass production can be considerable with favorable precipitation and can enhance

the probability of fire spread (Bunting and others 1987). Some cheatgrass communities have burned 2 or 3 times within 10 years (Boltz 1994). Repeated burning and invasion by cheatgrass removes Wyoming big sagebrush and inhibits its reestablishment (Rose and Eddleman 1994). As a result, some Wyoming big sagebrush steppe sites have converted to annual grasslands (Monsen and Kitchen 1994). Whisenant (1990) reports fire return intervals were as low as 3 to 5 years in portions of the Snake River Plains where cheatgrass now dominates. Furthermore, he estimates that cheatgrass has become a major herbaceous species in the West dominating over 400,000 km²; however, these estimates are disputed due to a lack of clear documentation as to how these conclusions were reached, as well as possible errors in the estimation of cheatgrass acreage (Connelly and others 2004).

Figure 3a—Pre- and post-settlement shrubland and woodland succession.

Size of the boxes represents the dominance of the communities in the Intermountain West. Heavy arrows indicate primary pathways of community succession.



Source: Miller and Tausch 2000.

Fire Regime and Fire Regime Condition Class (FRCC) are used to describe characteristics of a landscape and classify the FRCC when combined with estimates of historical fire regime reference values. Natural (historic) fire regime reference conditions exist for vegetation-fuel class composition, fire frequency, and fire severity for course-scale PNV groups. These reference conditions are the result of modeling with Vegetation Dynamics Development Tool (VDDT), literature review, field visits, and communication with regional experts (Hann and others 2004). PNV communities reference conditions were described for the three subspecies of big sagebrush in communities with and without trees. Additional sagebrush communities including silver sagebrush, bud sagebrush, and sand sagebrush among others were included in PNV descriptions. The reference conditions for these PNV provide general information regarding community description, fire regime description, vegetation type and structure, and fire frequency and severity. A sample FRCC reference condition for a cool mountain big sagebrush community is presented in Appendix H The reader is referred to the FRCC website for a complete, updated list of reference PNV groups at http://www.frcc.gov/pnvgSummaries.html. Reference conditions for PNV communities as a result of the FRCC project are useful in that they describe shrub community parameters. One weakness of these descriptions is the lack of literature based parameters and the subsequent reliance on expert experience for parameterization of these communities. However, the parameters agreed upon by the larger expert community should provide the basis of shrub behavior for future modeling efforts until new literature or better understanding of these systems is established.

Pinyon-Juniper Encroachment

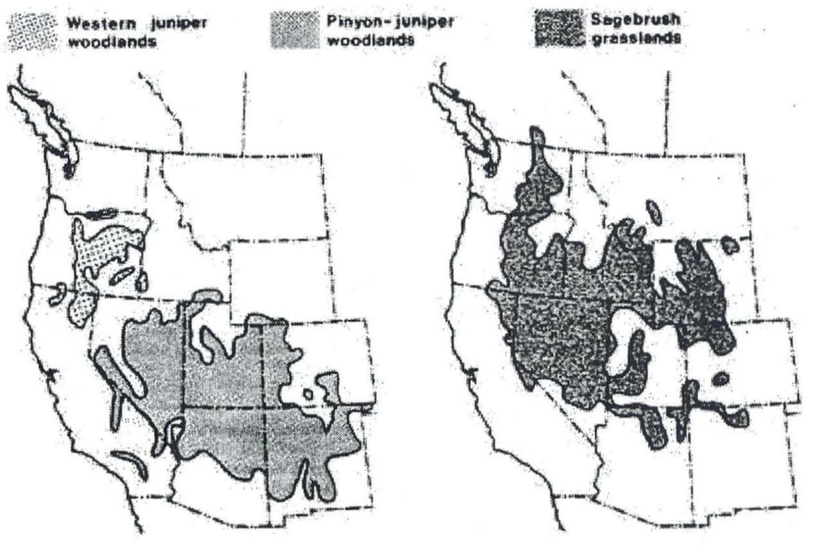
Expansion of woodland species including Utah juniper (*Juniperus osteosperma*), western juniper (*J. occidentalis*), single-leaf pinyon (*Pinus monophylla*), and two-needle pinyon (*P.edulis*) began in the late 1800's coinciding with Euro-American settlement and favor climatic conditions and increased livestock grazing (Miller and Rose 1995, 1999). Pinyon and juniper species are competitive across their range and can eliminate the understory component from invaded communities (Bates and others 2005, Johnsen 1962, Tausch and Tueller 1990, Miller and others 2000) and Bunting (1990) illustrates that the sagebrush-grasslands occupy much the same general region as the pinyon-juniper woodlands north of 37° latitude (fig. 3b). Miller and Tausch (2001) estimate pinyon-juniper communities have increased 10-fold since the late 1800s. Their increases in distribution and density pose a real threat to sagebrush communities in the Great Basin (Miller and Wigand 1994, Miller and Tausch 2001), and are the result of decreased fire frequencies, climate changes, historical patterns of livestock grazing, and increases in atmospheric CO_2 (Miller and Rose 1999, Miller and Tausch 2001). In addition, high sagebrush canopy cover resulting from decreased fire frequencies acts as a nurse plant for the establishment of western juniper (table 4) (Miller and Rose 1995).

Table 4—Mean growth rates for juvenile western juniper (2 to 30 years old) in three different establishment sites.

Establishment site	Growth rate (cm/yr)
Sagebrush	3.3
Western juniper	2.7
Interspace	2.4

Source: Miller and Rose 1995.

Figure 3b—Sagebrush grasslands and juniper woodlands (source Bunting1990).



To better capture these sites Miller and Rose (1995) applied a maturity class classification adapted from Blackburn and Tueller (1970 as cited in Miller and Rose 1995) to the western juniper sites in sagebrush communities of southeastern Oregon (table 5). General descriptions of the maturity classes at these study sites includes canopy cover, basal area, and density are found in Appendix I.

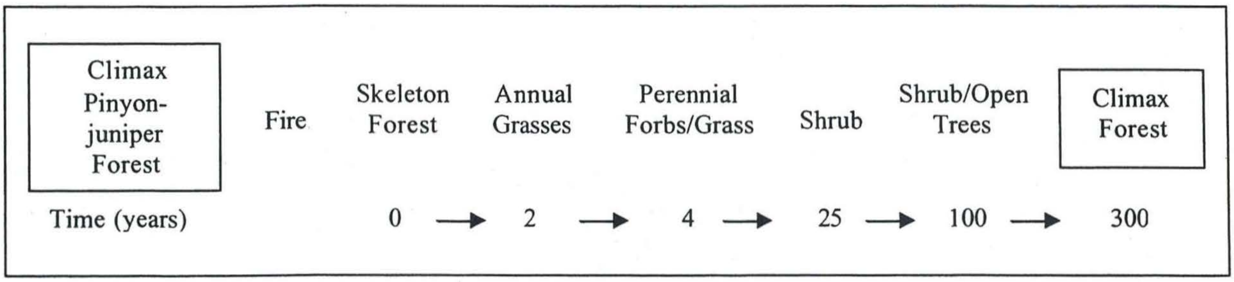
Table 5—Western juniper maturity classes in sagebrush communities of southeastern Oregon.

Maturity class	Description
Closed	Abundant adult trees generally>5 m tall and usually several trees >130 years old, with little understory, particularly on south slopes.
Intermediate	Abundant trees of all age classes with a more open canopy and an understory beginning to decline; trees >130 years old are rare.
Dispersed	Abundant young trees <2 m tall, a few adult trees but old trees absent, and a well developed understory

Source: Miller and Rose 1995.

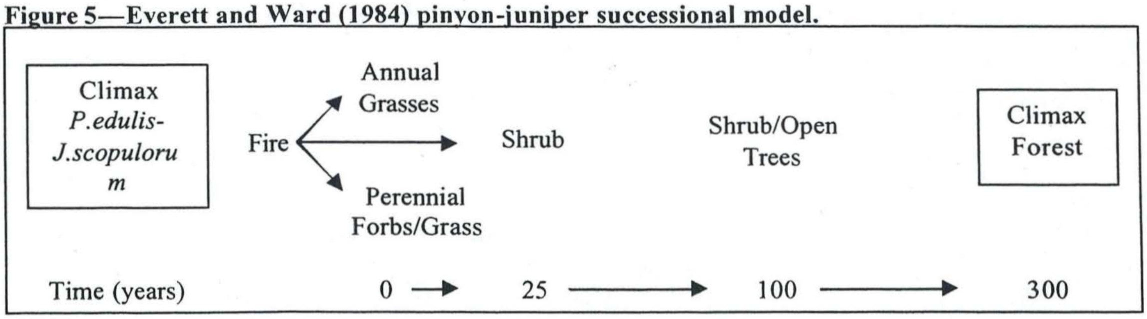
Several successional models have been proposed for pinyon-juniper woodlands. In Colorado Erdman (1969) documented a generalized successional model for this woodland type progressing from a skeletal forest to climax conditions (figure 4).

Figure 4—Erdman (1969) pinyon-juniper species successional model.



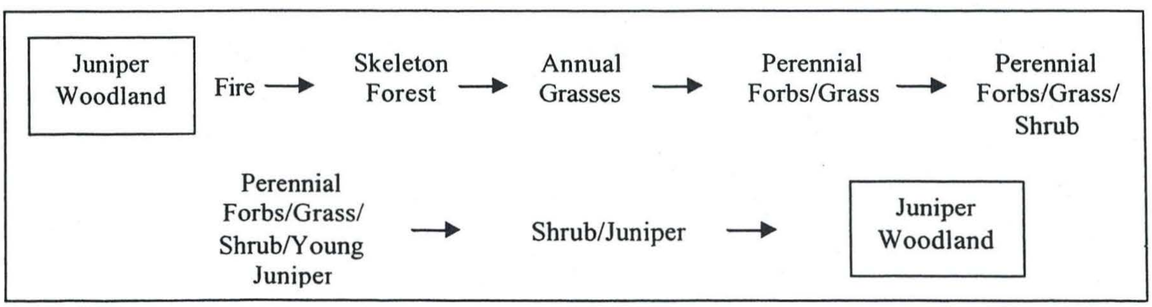
While useful, this generic view of succession in pinyon-juniper species stands has been challenged. Everett and Ward (1984) proposed a modification to the Erdman model, suggesting the "initial floristic" succession model of Egler (1954, as cited by Everett and Ward 1984, Tausch and others 1981, Koniak 1985) better described these systems. As a result, Everett and Ward (1984) modified the successional model of Erdman (1969) to represent multiple post-fire communities (figure 5).

Figure 5—Everett and Ward (1984) pinyon-juniper successional model.



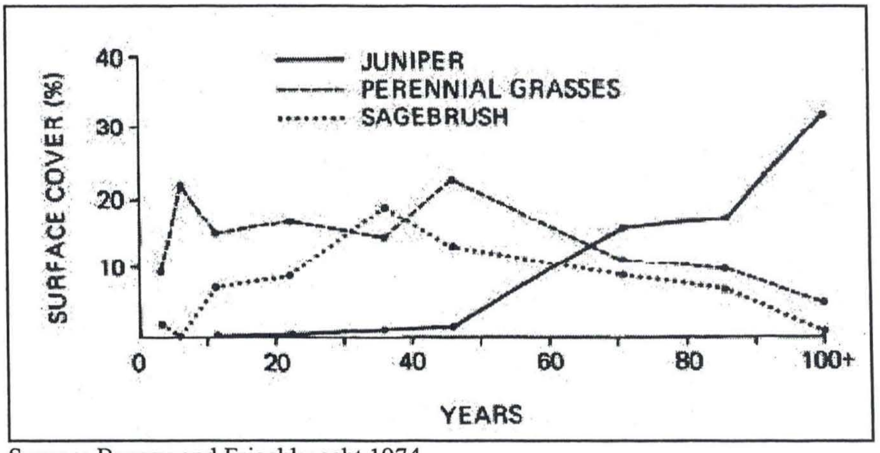
An additional succession model has been proposed for west-central Utah (Barney and Frischknecht 1974) (figure 6).

Figure 6—Barney and Frischknecht (1974) pinyon-juniper successional model.



Barney and Frischknecht (1974) found the annual stage reached maximum development in post-fire year 3 or 4, and was replaced by perennial grasses by post-fire year 5 or 6 if there was a fair remnant of native grasses in the pre-burn community. The shrub stage, in this case big sagebrush, began developing at post-fire year 11 but did not reach site dominance until year 35. Similarly, juniper occurred in year 11 but did not establish site dominance until approximately year 70 (figure 7, table 6). Two-needle pinyon pine occurred in minor amounts in the oldest stands (100+ years) and as such was not considered as part of the post-fire community (Barney and Frischknecht 1974).

Figure 7—Surface cover of Utah juniper, perennial grass, and big sagebrush following fire in the west-central mountains of Utah.



Source: Barney and Frischknecht 1974.

Table 6—Big sagebrush density, cover, and yield following fire[1].

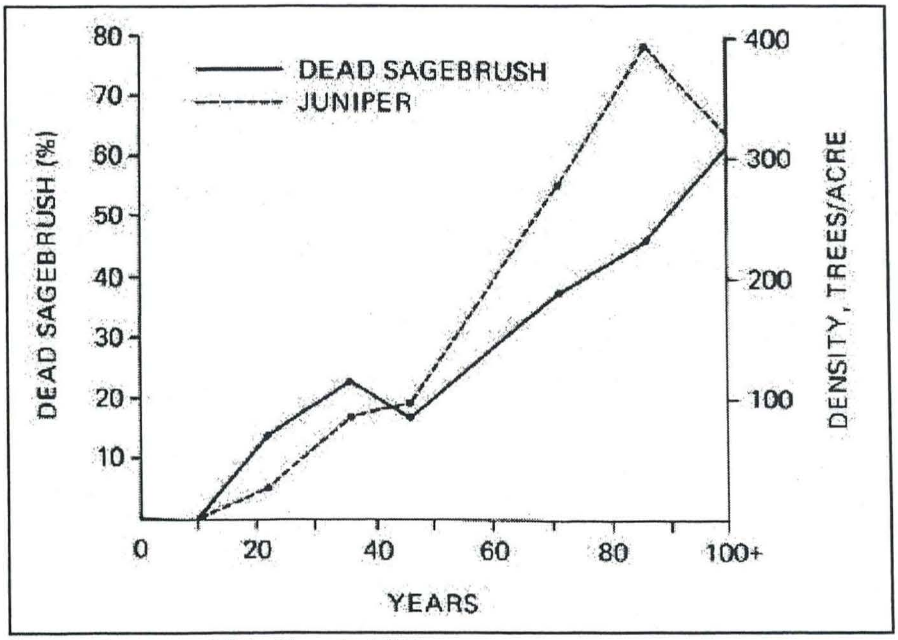
Approximate age of burn	Density (plants/plot)	Cover (percent)	Foliage yield (g/plot)
3	0.7	2.1	29.0
6	--	--	--
11	7.3	7.8	141.4
22	6.8	8.8	350.6
36	10.4	19.0	441.3
46	10.5	13.7	352.0
71	6.8	9.4	148.3
86	7.3	7.3	144.1
100+	1.5	1.2	19.5

Source: Barney and Frischknecht 1974.

[1] Shrub plot size equaled 100 ft^2.

Barney and Frischknecht (1974) documented a direct relationship between the frequency of dead sagebrush plants as juniper canopy cover increased (figure 8). No dead big sagebrush were found up to 11 years post-burn. Forty-six years following the burn 16.2% dead sagebrush were present and 100 years after fire 66.6% of the sagebrush was dead. The authors stated that as juniper dominance increases sagebrush will eventually reach a point of total elimination. Tausch and West (1995) and Miller and others (2000) further developed the inverse relationship between mountain sagebrush canopy cover and juniper canopy cover (figure 9).

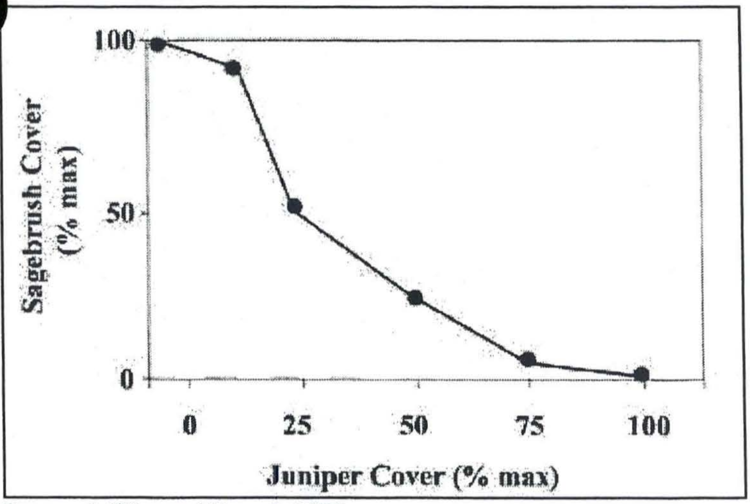
Figure 8—Juniper density (trees/acre), and percent dead big sagebrush following fire in west-central Utah.



Source: Barney and Frischknecht 1974.

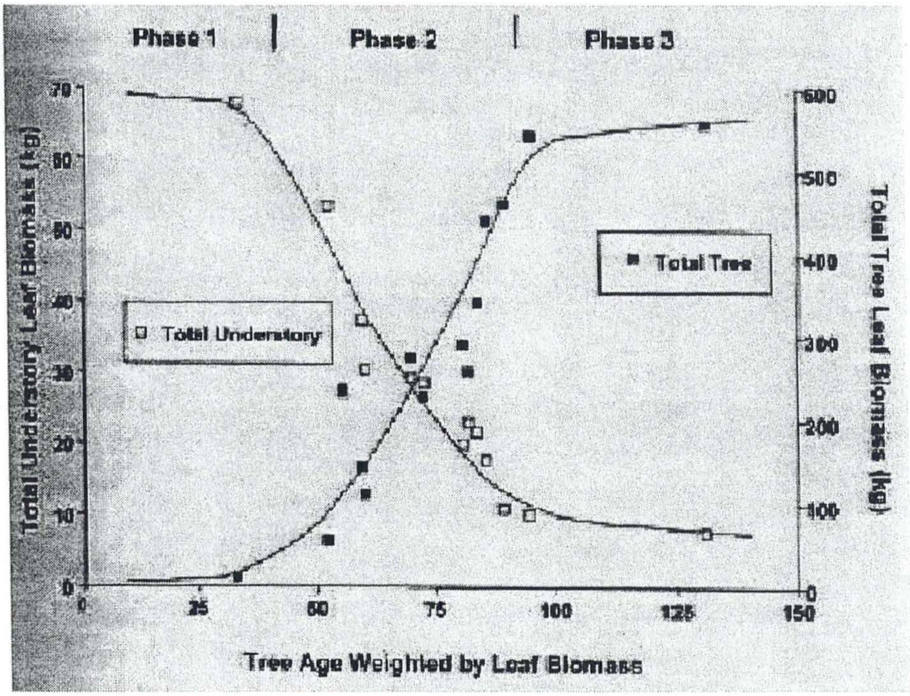
Pinyon pine species and juniper species are sensitive to fire and may be readily killed by fire when trees are less than 4 feet tall. However, as both species mature they become more resistant to fire (Evans 1988, Scher 2002) and as pinyon-juniper begin to dominate a site it becomes more resistant to fire. Juniper dominated stands compete directly with understory vegetation. As competition increases there is a subsequent reduction in herbaceous species reduces the fine fuels required to carry a ground fire (figure 10) (Bunting 1987).

Figure 9—The relationship between mountain big sagebrush and juniper cover derived from the work of Tausch and West 1995 and Miller and others 2000 (as cited by Miller and Tauch 2000).



Source: Miller and Tausch 2000.

Figure 10—Comparison of both the total tree leaf biomass (closed boxes) and total understory leaf biomass (open boxes) over time. The values are indexed by the range in leaf biomass weighted average age of pinyon for 14 plots in southwestern Utah[1].



Source: Miller and Tausch 2000.

[1] X-axis = sum of (average tree age/plot x Leaf biomass) across all plots/total leaf area of the stand.

Wisdom and others (2003) modeled the risk of pinyon pine and juniper displacement of sagebrush in the Great Basin (see section on GIS models for more detailed review of their findings and procedures). Only three ecological provinces were modeled because of problems with the land cover map. For the three ecological provinces large percentages (30 to 86%) of low sagebrush-mountain big sagebrush and mountain big sagebrush types were at high risk[3] of displacement; conversely, large percentages (56 to 72%) of Wyoming big sagebrush/basin big sagebrush and black sagebrush were at low risk. Their modeling exercise confirmed other findings (eg. Dealy and others (1978) and Burkhardt and Tisdale (1976) suggested the entire mountain big sagebrush type in western juniper areas might be susceptible to juniper invasion) that most if not all of the mountain big sagebrush and low sagebrush/mountain big sagebrush types are at the greatest risk to conifer encroachment.

As shown above there is no doubt that pinyon and juniper will continually increase in stature and expand into many sagebrush habitats without fire. The prediction of sites where conditions are conducive to pinyon and juniper invasion is difficult because of compensating factors (Dealy and others 1978) and changing environmental conditions (climate change). Dealy and others (1978) state that even a brief personal encounter with variability in soils, climate,

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[3] The risk categories assigned were (from Wisdom 2003):
Low . the probability that pinyon/juniper will displace existing sagebrush cover types within 30 yrs is minimal; little or no pinyon/juniper is likely to be present in the overstory of these sagebrush stands at the current time.
• Moderate . the probability that pinyon/juniper will displace sagebrush within 30 yrs is likely, but less so than sagebrush at high risk; pinyon/juniper is likely to be a minor to common component of the overstory of these stands at the current time. This class represents a transition phase in the conversion of sagebrush cover types to pinyon/juniper woodlands. Sagebrush stands are expected to cross the threshold from low risk to high risk relatively quickly. Therefore, the total area in this class is expected to be small when compared to the other classes.
• High . the probability that pinyon/juniper will displace sagebrush within 30 yrs is very likely; pinyon/juniper is likely to be a common to dominant component of the overstory of these stands at the current time.

topography, management history, vegetation, etc. conveys the complexity of unraveling the ecology of western juniper areas and the same could be stated for other pinyon/juniper areas. Some conditions will be more conducive to pinyon and juniper occurrences than others, but we now lack the ability to define the limits of those conditions and their combinations. In modeling the risk of pinyon-juniper invasion within sagebrush cover types Wisdom and others (2003) used proximity of sagebrush from pinyon-juniper as a critical factor. In other words, if pinyon or juniper were in close proximity the likelihood of invasion greatly increased. Other factors in their model were precipitation, elevation, land cover class, ecological province and landform. What all agree on is that the combination of factors or compensation is key and if fires occur at a MFRI of about 100 years the pinyon/juniper communities will generally not displace the sagebrush communities.

Conifer Encroachment

Limited documentation supports the encroachments of other woody species. Mountain big sagebrush is a climax dominant species, which is often associated with forest species such as Douglas-fir (*Pseudotsuga menziesii*), ponderosa pine (*Pinus ponderosa*), lodgepole pine (*Pinus contorta*), and western juniper (*Juniperus occidentalis*) (Beetle 1961, Beetle and Johnson 1982, Johnson and others 1994). Fire suppression has been a factor in the invasion of mountain big sagebrush communities by lodgepole pine, and Douglas-fir (Bunting 1990, Burkhardt and Tisdale 1976, Miller and Rose 1998, Beetle 1961, Arno and Gruell 1983). In southern British Columbia, mountain big sagebrush occupies openings in subalpine fir forest (*Abies lasiocarpa*). Many of these communities are considered edaphic or topographic climax communities (Beetle 1961, Beetle and Johnson 1982, McLean 1970).

Climate Variation

Climate variation has been cited as a contributing factor to the conversion of sagebrush communities to woodland communities and forest species (Miller and Rose 1999, Miller and Tausch 2001, Connelly and others 2004). Miller and Rose (1995, 1999) stated that large scale increases in western juniper cover coincided with a period of warmer, wetter climatic conditions. Hanson and others (1993) using three general circulation models and the rangeland model SPUR, found temperature and precipitation had a greater influence on production than atmospheric carbon dioxide (CO_2). Svejcar and others (2003) using rain-out shelters showed negative effects of changing the precipitation patterns to a spring pattern rather than winter moisture pattern for a sagebrush community. Bachelet and others (2001) investigated seven climate senerios with increase in temperature ranging from 2.8 to 6.6^0 C. Simulation results showed increased temperatures and precipitation and hence expansion of woodland and forest species into sagebrush communities (Neilson and others 2005). Neilson and others (2005) suggest the synergistic interaction between changing fire regimes, woody species expansion, and climate change could rapidly alter future sagebrush communities of the Great Basin. Enhanced climate models are continuely becoming available as our understanding of this phenomena increases; this imprecision places limitations on the power of predictions made from process models. Due to these, and other, complexities a thorough discussion of the influences of climate change on sagebrush ecosystems is beyond the scope of this paper.

Agricultural Conversion

Conversion of sagebrush communities to croplands or urban areas is the most severe change occurring in sagebrush habitats. Obviously, in areas where urbanization has taken place

there is little hope of future restoration. Previous estimates of potential sagebrush habitat converted to urban or agricultural uses were 3 percent for the Great Basin, and 15 percent for the Sagebrush Steppe (Klopatek and others 1979 as cited by Connelly and others 2004). Connelly and others (2004) have revised these estimates with updated land use maps and satellite imagery. Conversion of sagebrush communities is now estimated at 6% (7,398 km^2) of the Great Basin Sagebrush region, and 17% (59,161 km^2) of the Sagebrush Steppe. This small scale assessment points out the chronic destruction of potential sagebrush habitat as a result of urban and agricultural expansion.

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SAGEBRUSH SPECIES: A REVIEW OF AUTECOLOGICAL AND SYNECOLOGICAL INFORMATION

Tall Sagebrush Species

The following section details the specific physiologic, morphologic, and ecological characteristics of four tall sagebrush species as delineated by West and Young (2002). These species are found throughout the Great Basin, Colorado Plateau, and the Intermountain Sagebrush Steppe.

Sand Sagebrush (Artemisia filifolia)

Sand sagebrush (*Artemisia filifolia* Torr.) (USDA 2004) is widely distributed throughout western North America (McKell and Goodwin 1975, Turner 1982). Its range extends from Nevada, northeast to Wyoming, the Black Hills of South Dakota, western Nebraska, and south to Texas and Mexico (McArthur and others 1979, McArthur and Stevens 1986). Across this broad geographic range, this edaphic climax species (Daley 1972) characteristically occupies dry areas with deep sandy soils (Rasmussen and Brotherson 1986) and is described as the most abundant shrub on dunes and sand hills from Nebraska to Arizona (McArthur and others 1979).

Physiology and Morphology

Sand sagebrush is a round, freely branching, woody shrub growing up to 5 feet tall. Leaves are entire or pinnately divided into filiform divisions from 1.2 to 2.0 inches long and less than 0.5 mm wide. Narrow panicles support numerous nodding heads with 2 or 3 fertile, pistillate ray flowers and 1 to 6 perfect but sterile disk flowers (McArthur and others 1979).

The growing period for sand sagebrush across the Great Plains is from February to November (Savage and Heller 1947). Flowering varies depending on site location; beginning in August to November in Arizona, August to September in New Mexico, and August to October in Kansas (Kearney and others 1960, Martin and Hutchins 1981, Bare 1979). Stephens (1973) documented fruit ripening from September to October in the Central Plains.

Reproduction

Sand sagebrush reproduces both vegetatively and by seed (Jackson 1965, Vermeire and others 2001, Stickney 1989). Profuse sprouting occurs following spring and fall burns (Vermeire and others 2001). Seed dispersal and seed bank characteristics require further study (McWilliams 2003).

In laboratory trials sand sagebrush germination only occurred when seeds were planted at 0.5 inch, all other planting depths were deeper; and it took 17 days before seedling emergence (Bridges 1941). Vines (1960) found germination rates to be from 40 to 50 percent.

On a mine reclamation site in Utah, Ferguson and Frischknecht (1985) documented 75 percent survival rate for three-year-old sand sagebrush seedlings with an average height of 36 inches and 42-inch crown diameter.

Ecological Information

Sand sagebrush is found from elevations of 2,000 to 6,000 feet (Johnson 1987) with annual precipitation ranging from 8 to 10 inches in Utah (Rasmussen and Brotherson 1986) and up to 24 inches in Oklahoma (Vermeire and others 2001). Species associated with sand sagebrush sites in the Great Basin include blue grama (*Bouteloua gracilis*), prairie sandreed

(*Calamovilfa longifolia*), sand bluestem (*Andropogon hallii*), and pricklypear (*Opuntia* spp.) (Davis and Bonham 1979, Herbel 1979, O'Meilia and others 1982). In Colorado and Wyoming, Costello (1944) describes a sand sagebrush type, which includes blue grama, needle-and-thread (*Hesperostipa comata*), red threeawn (*Aristida purpurea* var. *longiseta*), sand dropseed (*Sporobolus cryptandrus*), prairie sandreed, and sand bluestem. Great Plains associates not already mentioned include western wheatgrass (*Pascopyrum smithii*), sun sedge (*Carex heliophila*), perennial ragweed (*Ambrosia psilostachya*), white sagebrush (*A. ludoviciana*), soapweed yucca (*Yucca glauca*), galleta (*Pleuraphis jamesii*), and big bluestem (*Andropogon gerardii*) (Costello 1944, Davis and Bonham 1979, Herbel 1979, O'Meilia and others 1982, Kaul and Keeler 1980). Furthermore, in Texas, Secor and others (1983) documented a sand shinnery oak (*Quercus havardii*)/sand sagebrush type with important species including purple threeawn (*A. purpurea*), black grama (*B. eriopoda*), false buffalograss (*Monroa squarrosa*), and dropseed species (*Sporobolus* spp.). Sand sagebrush sites are generally less diverse but denser than adjacent communities (McArthur and Stevens 1986). Humphrey (1955) noted these sites are more open than adjacent big sagebrush communities (Humphrey 1955).

Sand sagebrush is found primarily in late seral communities. In the sand hills of Colorado, Ramaley (1939) documented a subclimax sand sagebrush community, while Daley (1972) recorded sand sagebrush as part of an edaphic climax community of the mixed-grass prairie. In Texas, Diamond and others (1987) describe the sand sagebrush/mid-grass series on the rolling plains, and a honey mesquite (*Prosopis glandulosa*)-sand sagebrush series.

In Wyoming, Renner and Allred (1962) described sandy range sites and their associated productivity (table 7). Table 8 describes species composition for Wyoming sandy range sites as

documented by Renner and Allred (1962). The relative vegetative composition of a sand sagebrush site in Utah is presented in table 13.

Table 7—Description of sandy range sites in Wyoming.

Range site condition	Species	Sand sagebrush cover (%)	Productivity (lb/ac)
Poor	Annuals, cacti (*Opuntia* ssp.), sand dropseed, blue grama, and needle-and-thread	35	400 to 1750
Fair	Annuals, cacti (*Opuntia* ssp.), sand dropseed, blue grama, needle-and-thread, and prairie sandreed	35	750 to 1,500
Good	Prairie sandreed, blue grama, needle-and-thread, sand dropseed, sand bluestem, and annuals	15	1,000 to 2,250

Source: Renner and Allred 1962.

Table 8—Relative vegetative cover of a sand sagebrush community in Utah.

Site attributes	Average percent composition
Litter	89.7
Cryptogams	48.8
Shrubs	52.1
Perennial grass	33.7
Annual grass	66.2
Perennial forbs	19.2
Annual forbs	71.8
Total cover	24.2

Source: Rasmussen and Brotherson 1986.

Sand sagebrush communities are located on sandy soils with low silt and clay content (Secor and others 1983, Daley 1972). McArthur and Stevens (1986) reported that sand sagebrush can accumulate minerals well above levels found in the soil, which is helpful in the poor soils sand sagebrush occupies.

Disturbance Response

Sand sagebrush is top-killed by fire (Launchbauch and Owensby 1978). Vermeire and others (2001) found fire-induced mortality was less than 10 percent regardless of season. Following a fall burn 94 percent of burned plants resprouted, while 92 percent of the plants

resprouted after a spring burn. Canopy and structure alteration were the primary effects of the prescribed burns. Spring burns reduced canopy area and volume by more than 90 percent with fall burn reductions of 75 percent (Vermeire and others 2001). In northern Texas, Jackson (1965) documented an abundance of sand sagebrush seedlings following a March burn in a sand sagebrush/shinnery oak community. However, a spring burn in the same community type followed by 2 years of drought was characterized by sparse canopy cover and wind erosion.

Past grazing has altered normal successional patterns in many sand sagebrush sites. In many parts of the southwest, sand sagebrush/bluestem (*Andropogon* spp.) form an edaphic climax community (Johnston 1987, Moir 1983). Successional trends on sand dune sites in southern New Mexico have been well documented and are presented in table 9.

Table 9—Sand dune community succession in southern New Mexico.

Successional stage	Description
Mat stage	Rapidly growing drought-escaping species colonize dunes.
Ruderal weed stage	Characterized by rapidly growing weedy species responding to increased moisture. Aster, annual bursage (*Ambrosia acanthicarpa*), annual sunflower, and buffalo gourd (*Cucurbita foetidissima*).
Drought enduring species increase; erosion decreases	Sand sagebrush, broom snakeweed, red threeawn, and desert baileya (*Baileya multiradiata*) are common.
Dropseed stage	Grasses increase after 2 to 3 years of "ample precipitation." Sand dropseed, mesa dropseed (*S. flexuosus*), giant dropseed (*S. giganteus*), swithchgrass (*Panicum virgatum*), and red threeawn are common.
Black grama climax	Site dominated by black gramma

Source: Campbell 1929.

Over the past 100 years, some southwest grasslands formerly dominated by blue grama are now dominated by mesquite (*Prosopis* spp.), broom snakeweed, sand shinnery oak, and/or sand sagebrush (Davis and others 1974). This shift in species dominance is attributed to many

years of overgrazing because generally sand sagebrush increases under moderate and heavy grazing, while declining under light grazing.

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Basin Big Sagebrush (Artemisia tridentata ssp. tridentata)

Big sagebrush (*Artemisia tridentata* Nutt.) (USDA 2004) is widespread and of great economic importance (Freeman and others 1991). Kartesz (1997) recognized five big sagebrush subspecies (table 10). Edaphic and climatic factors influence cover type distribution, while soil depth and seasonal wetness dictate subspecies type (Winward and Tisdale 1977); however, that is not to say the breaks between these subspecies is always easily discernable. The dominant big sagebrush subspecies, basin big sagebrush, mountain big sagebrush, and Wyoming big sagebrush, will be treated separately in this report. Basin big sagebrush found commonly in valley bottoms and lower foothills extends from the Great Basin to upper timberline from Washington, east to the Dakotas, and south into California, Arizona, and New Mexico (Welsh and others 1987). It is also found in small stands east of the Cascade Mountains in Oregon (Winward 1980). This climax dominant species is found on deep, fertile soils (Pechanec and others 1954, Young and Evans 1981); and is situated between the other big sagebrush subspecies along the soil moisture and soil temperature gradients (Appendix G) (West and Young 2002).

Table 10—Big sagebrush subspecies

Scientific name	Common name
Artemisia tridentata Nutt. ssp. *tridentata*	Basin big sagebrush
Artemisia tridentata Nutt. ssp. *spiciformis* (Osterhout) Kartez & Gandhi	Big sagebrush
Artemisia tridentata Nutt. ssp. *vaseyana* (Rydb.) Beetle	Mountain big sagebrush
Artemisia tridentata Nutt. ssp. *wyomingensis* Beetle & Young	Wyoming big sagebrush
Artemisia tridentata Nutt. ssp. *xericensis* Winward ex Rosentreter & R. Kelsey	Big sagebrush

Source: USDA 2004, Kartesz 1994.

Ecotypes have been documented within each subspecies (Meyer and Monsen 1992). In addition, hybrids between basin big sagebrush and mountain big sagebrush are confirmed (Graham and others 1995, McArthur and others 1998). McArthur (2000) stated that hybridization is common among sagebrush and may be a mechanism to facilitate occupation of changing habitats throughout evolutionary history.

Physiology and Morphology

Basin big sagebrush is an erect shrub reaching from 3 to 10 feet tall (Weiss and Verts 1984). Height variability is related to soil moisture with maximum stature being reached on deep, well-drained soils in sheltered areas (Beetle 1960). This subspecies commonly reaches 40 to 50 years old and may exceed 100 years of age (Tirmenstein 2005).

The root system is well adapted to extract moisture from all zones of the soil profile (Britton and others 1981, Tweit and Houston 1980). Tap roots penetrate deep into the soil profile to extract moisture and minerals well below associated herbaceous material during drought conditions. In addition, lateral roots radiate from the plant 4 to 6 inches below the surface and can extend from 10 to 16 feet in older plants. Tertiary roots then radiate off the lateral roots in a "bottlebrush" arrangement to further mine the soil of moisture and minerals (Winward 2004). Furthermore, the roots are colonized by the *Glomus* genius of mycorrhizal fungi (Rosentreter and Jorgenson 1986).

In Utah, Eckert (1957) documented vegetative growth beginning in early June and decreasing by the end of June as reproductive bud and shoot growth begins. Reproductive shoots reached maximum height and began to bud in late July (Eckert 1957). Seasonal development of basin big sagebrush in Washington is presented in table 11. Generally, flowers develop from late August to October (Shumar and Anderson 1986). Mueggler (1956) found high elevation ecotypes tend to flower and set seed earlier than valley ecotypes.

Table 11—Phenology of basin big sagebrush in Washington.

Approximate date	Phenological event
March 4	No evidence of new shoot growth
April 1	1.5 to 2.0 inches of new shoot growth
April 30	4.0 to 5.0 inches of new shoot growth
June 2	4.0 to 10.0 inches of new shoot growth
July 1	18.0 inches of new shoot growth
August 1	Remaining leaves mainly in panicle or at branch tips

September 1	Flower buds formed
October 3	Pollination beginning
October 31	Fruits immature
February 27	Dissemination ended, inflorescence brittle
March 15	Buds swelling

Source: (DePuit and Caldwell 1973).

Reproduction

All subspecies of big sagebrush reproduce by seed (Sheehy and Winward 1981). The wind-pollinated flowers produce viable seed 2 to 3 years after plant establishment (Goodrich and others 1985). Basin big sagebrush seed viability is less than 5 years in storage (Mueggler 1956). The majority of big sagebrush seed (90 percent) falls within 30 feet of the parent plant with maximum seed dispersal reaching 108 feet (Shumar and Anderson 1986, Goodrich and others 1985). The rate of mature seed dispersal depends on wind and storm activity (Shumar and Anderson 1986).

Seedlings germinate in a variety of temperatures. Unstratified seeds required 2 to 3 days to germinate at all temperatures (Meyer 1994). In the Mojave Desert, Meyer and others (1990) and Mueggler (1956) documented seedling germination during mild winters. Seedling survival depends on precipitation with most seedlings emerging soon after snowmelt (Owens and Norton 1990, Meyer and others 1990); and is enhanced when seedlings grow under mature shrubs and are in ungrazed or sheltered areas (Owens and Norton 1992, Personius and others 1987).

Basin big sagebrush produces more seed than Wyoming big sagebrush (Mueggler and Stewart 1980). Harniss and West (1973) found adequate basin big sagebrush seed was produced each year, even at the lowest germination rates. On burned sites emergence of basin big sagebrush was reduced in comparison to Wyoming and mountain big sagebrush (Cook 1963).

Ecological Information

Basin big sagebrush grows on fertile sites with deep soils. Many of these sites have been converted to farmland (Pechanec and others 1954, Young and Evans 1981). Basin big sagebrush sites are characterized by precipitation ranging from 10 to 18 inches annually with elevations from 100 feet, in Oregon, to over 7,000 feet in Utah (Collins 1984, Beardall and Sylvester 1976, Hull and others 1952, Young and Evans 1981). This climax species rarely invades other vegetation types (Chaplin and Winward 1982, Dealy 1971, Hironaka and others 1983, Hopkins and Kovalchik 1983, Neuenschwander 1980, Tweit and Houston 1980, Zschaechner 1985) and prefers seasonally dry, well-drained, deep soils of the plains, valleys, and foothills (Beardall and Sylvester 1976). Thus, basin big sagebrush is often found on more mesic sites than other big sagebrush subspecies (Beetle 1960, Meyer 1994) in areas with high water tables or deep moisture accumulation (Striby and others 1987). Basin big sagebrush also requires a longer frost-free period than other subspecies (Monsen and McArthur 1985).

In Colorado, canopy cover in near pristine basin big sagebrush/basin wildrye (*Leymus cinereus*) sites was from 15 to 25 percent (Baker and Kennedy 1985) Productivity in disturbed basin big sagebrush/bluebunch wheatgrass sites in Idaho ranged from 500 lb/ac to 1,500 lb/ac (Dealy and others 1981). Production for two basin big sagebrush winter range communities in Colorado is presented in table 12.

Table 12—Productivity of two basin big sagebrush communities in Colorado.

Lifeform	Basin big sagebrush/bluebunch wheatgrass habitat type (lb/ac)	Basin big sagebrush-black greasewood/western wheatgrass habitat type (lb/ac)
Shrubs	1,309	1,213
Graminoids	132	27
Forbs	29	5

Source: Tiedeman and others 1987.

Tisdale (1994) describes the basin big sagebrush cover type in the Great Basin as frequently bordering the other two big sagebrush subspecies. Site characteristics for Great Basin communities within this cover type are presented in table 13.

Table 13—Basin big sagebrush site characteristics

Lifeform	Percent composition by weight	Site productivity (lb/ac)
Shrubs	20	
Grasses	50	
Forbs	20	
		700 to 1,900
Ground cover		
Litter	25 to 30	
bare ground	50	

Source: Tisdale 1994.

In the Great Basin, basin big sagebrush communities include the following graminoids: bluebunch wheatgrass (*Pseudoroegneria spicata*), Thurber needlegrass (*Achnatherum thurberianum*), needle-and-thread (*Hesperostipa comata*), Idaho fescue (*Festuca idahoensis*), and thickspike wheatgrass (*Elymus laceolatus*) (McMurray 1989). Associated shrubs include yellow rabbitbrush (*Chrysothamnus viscidiflorus*), antelope bitterbrush (*Purshia tridentata*), and gray horsebrush (*Tetradymia canescens*) (Tisdale 1994). In the Rocky Mountains and Wyoming Basin dominant grasses include bluebunch wheatgrass and western wheatgrass (*Pascopyrum smithii*). Important understory associates are fringed sagebrush (*Artemisia frigida*), broom snakeweed (*Gutierrezia sarothrae*), prairie junegrass (*Koeleria macrantha*), and blue grama (*Bouteloua gracilis*) (Fisser 1986, Tiedeman and others 1987). Along the Colorado Plateau big galleta (*Hilaria jamesii*), blue grama, and sand dropseed (*Sporobolus crytandrus*) are important species (Francis 1986). Other associated species include cheatgrass (*Bromus tectorum*) and yellow rabbitbrush (Collins 1984, Hopkins and Kovalchik 1983).

Basin big sagebrush is most abundant on sandy soils (Striby and others 1987), and is not considered alkaline tolerant. However ecotypes were documented growing in association with

salt-tolerant plants including shadscale (*Atriplex confertifolia*), black greasewood (*Sarcobatus vermiculatus*), and saltgrass (*Distichlis* spp.) (Bernard and Brown 1977, Hopkins and Kovalchik 1983). In Utah, Ward (1953) found basin big sagebrush sites to be slightly alkaline whereas mountain big sagebrush sites where slightly acidic.

Disturbance Response

Most fire kills basin big sagebrush. Sagebrush foliage exposed to temperatures above 195^0 F for more than 30 seconds dies (Britton and Clark 1985). Unburned plants may survive fire by occupying areas were the soil is thin and rocky or herbaceous cover is low inhibiting fire spread (Bushey 1987). Seed production from unburned plants coupled with seed transported by wind, water, and animals contribute to site regeneration (Goodwin 1956, Johnson and Payne 1968, Tisdale and Hironaka 1981). The rate of recovery for these communities depends on the season of burn, post fire precipitation patterns, and the amount of inter-species competition (Britton and Clark 1985, Daubenmire 1975, Zschaechner 1985). However, seedling establishment may be delayed until the appropriate moisture conditions exist (Humphrey 1984).

Fire history for basin big sagebrush is not well documented. The fire interval in these communities is variable, dependent on weather, available fuels, and topography. Fire in these types is generally stand replacing (Sapsis and Kauffman 1991). Of the big sagebrush subspecies, Britton and Clark (1985) considered mountain big sagebrush to be the most flammable, followed by basin big sagebrush, and Wyoming big sagebrush. Tisdale and Hironaka (1981) and Winward (1985) consider fire a relatively uncommon event in xeric Wyoming big sagebrush types. Fire return intervals for big sagebrush subspecies are presented in table 14.

Table 14—Fire return interval for big sagebrush subspecies.

Subspecies	Fire return interval in Years
Artemisia tridentata ssp. *tridentata*	12-43 (Sapsis 1990)
Artemisia tridentata ssp. *vaseyana*	15-40 (Arno 1980, , Burkhardt and Tisdale 1976) 10 to 70 mean of 40 (Vincent 1992, Young and Evans 1981)
Artemisia tridentata ssp. wyomingensis	32 to 70 *Wright and Bailey 1982* dry sites 50 (*Wright and others 1979)*

Source: Sapsis 1990.

There is a dearth of literature regarding long-term effects of fire on big sagebrush communities. McArthur and others (1985) hypothesize that post-fire recovery of basin big sagebrush is intermediate between that of the other two subspecies based on the relative productive potential and moisture regime of these sites. This generalization does not hold true for all circumstances however, Winward (1985) documented big sagebrush regaining site dominance 5 to 10 years following burning; while in an Idaho a mountain big sagebrush community did not achieve site dominance until 18 years following fire (Blaisdell 1953, Blaisdell and others 1982, Harniss and Murray 1973). Johnson (1969) found basin big sagebrush regained pre-treatment canopy cover on grazed sites 17 years after herbicide application. The duration of reduced big sagebrush cover documented by Bunting and others (1987) is presented in table 15.

Table 15—Duration of reduced big sagebrush subspecies canopy cover following burning.

Subspecies	Years of reduced canopy cover
Mountain big sagebrush	15 to 25
Wyoming big sagebrush	25 to 50

Source: Bunting and others 1987.

Changes in fire frequency have removed basin big sagebrush from many areas in the Great Basin and Columbia River drainages (Bunting 1990). The introduction of cheatgrass and other annuals have increased fine fuels so fire now carries through stands that previously would not have burned. As a result, fire intervals are as low as 5.5 years in some stands, which does not provide a long enough fire free interval for the establishment of basin big sagebrush (Bunting

1990, Boltz and others 1987). Furthermore, big sagebrush subspecies are associated with *Glomus* species mycorrhizal fungi, which may be necessary for seedling establishment. Repeated burning and increases in nonmycorrhizal cheatgrass may eliminate the fungi and inhibit sagebrush seedling establishment (Rosentreter and Jorgenson 1986). In addition, these fires are often occurring during the early summer when native perennial grasses are easily damaged (Wright 1985). Winward (1985) suggest that if fire enters sites before young sagebrush plants reach reproductive maturity, two or three reburns may be all that are need to create a stable cheatgrass community.

While studies focusing on the use of fire as an ecological agent in basin big sagebrush communities is lacking (Sapsis 1990), numerous studies have focused on the relationship between fire and big sagebrush in general. Prescribed burns to control sagebrush species were most successful in mountain big sagebrush followed by basin big sagebrush and Wyoming big sagebrush (Britton and others 1981). This was likely the result of higher fuel loads at the mountain and basin big sagebrush sites. In Nevada, Beardall and others (1976) documented the greatest sagebrush removal from spring or late fall fires. Bunting and others (1987) and Hodgkinson (1989) expressed concern that summer burns to control sagebrush species would result in exposed soil, which often leads to erosion.

Britton and others (1981) contend that for successful prescribed fire in big sagebrush communities 200 to 300 lb/ac of herbaceous fuel is necessary and sagebrush should comprise at least 20 percent canopy cover. In contrast, Beardall and Sylvester (1976) recommend 600 to 700 lb/ac of fine fuels, at least 33 percent sagebrush canopy cover, less than 60 percent relative humidity, and wet soils to burn sagebrush sites in Nevada. A comparison of winter broadcast burn characteristics for big sagebrush communities in southern Idaho is presented in table 16. In

Nevada, Bushey (1985, 1987) documented the conditions of a successful September prescribed burn in a basin big sagebrush/bluebunch wheatgrass-Sandberg bluegrass community of Nevada (table 17). The average fuel load for basin big sagebrush is presented in table 18.

Table 16—Winter broadcast burn characteristics for southern Idaho big sagebrush communities.

Conditions	Fire successful	Fire unsuccessful
Canopy cover (percent)	72.1	60.0
Density (plants/ha)	114,296	121,020
Biomass (g/plant)	1,634	1,496
Shrub height (cm)	103.8	108.3
Basal diameter (cm)	3.8	3.2
Distance between plants (cm)	15.4	37.5
Temperature (C)	9.0	9.0
Relative humidity (percent)	49.3	46.6
Windspeed (km/h)	8.3	6.6
Fuel moisture (percent)	37.0	38.0

Source: Neuenschwander 1980.

Table 17—Fuel and environmental conditions of a prescribed burn in a big sagebrush community.

Attributes	Conditions
Temperature (F)	70
Relative humidity (percent)	15
Windspeed (mph)	1-3
Soil moisture (percent)	8
Herbaceous fuel load (ton/acre)	1.18
Herbaceous fuel depth (feet)	1.2
Live sagebrush moisture (percent)	93

Source: Bushey 1985.

Table 18—Average fuel load for basin big sagebrush.

		Fuel load (lb/ac)		
Species	Leaves	1 hour	10 hour	100 hour
Basin big sagebrush	749.4	1070.6	1249.1	1427.5

Source: Frandsen 1983.

In a study by Sapsis and Kauffman (1991) a basin big sagebrush/Idaho fescue-bluebunch wheatgrass community was burned in both the fall and spring to investigate fuel consumption and fire behavior with different fuel moisture and plant phenology. Flame length for the fall burn averaged more than 13 feet as compared to less than 7 feet for the spring burn. The fall burn spread 6 times faster than the spring burn despite high relative humidity and lower temperatures. Virtually all aboveground biomass was consumed in the fires, with approximately

85 percent of the 10-hour fuels burned in the fall as compared to 52 percent burned in the spring (table 19 and 20). Thus, stand-replacing fire in basin big sagebrush communities varies in terms of fuel consumption and fire behavior, and is partially dependent on fuel characteristics, weather, and topography.

Table 19—Residual fuel loads and fuel consumption of prescribed burns in eastern Oregon.

Treatment	Residual fuel load (Mg/ha)				
	Fine fuels	1 hour	10 hour	100 hour	Total biomass
Fall prescribed burn	0.23	0.15	0.32	0.09	0.79
Spring prescribed burn	0.23	0.20	0.49	0.08	1.00

Source: Sapsis and Kauffman 1991.

Table 20—Fuel consumption for prescribed burns in eastern Oregon.

Treatment	Fuel consumption (Mg/ha)[1]				
	Fine fuels	1 hour	10 hour	100 hour	Total consumption
Fall prescribed burn	3.64 (94.54)	1.65 (91.66)	1.90 (85.59)	2.63 (96.69)	9.8 (92.54)
Spring prescribed burn	2.76 (92.31)	0.66 (76.74)	0.54 (52.43)	1.27 (94.07)	5.23 (83.95)

[1] Numbers in parentheses are the percent fuel consumption.
Source: Sapsis and Kauffman 1991.

Another study by Sapsis (1990) in east-central Oregon occurred in a basin big sagebrush/Idaho fescue-bluebunch wheatgrass community. The objectives were to quantify fuel loads, environmental conditions, fire behavior, and response of these communities to spring and fall burning. Under spring burning basin big sagebrush increased one year post-fire; while under fall burning no basin big sagebrush increases were noted 2 years post-treatment. In addition, fall burning completely removed basin big sagebrush whereas spring burning decreased sagebrush density by 84 percent. This study suggests fall burning is more severe and is more effective in reducing basin big sagebrush.

Winter burning of basin big sagebrush communities is possible if over 50 percent canopy cover is evenly distributed. The distance between plants must not exceed 50 percent of the

plants average height (Neuenschwander 1980). This technique protects fire sensitive understory species. Environmental conditions to achieve this type of prescribed burn are presented in table 20.

Table 20—Environmental conditions of a winter prescribed burn.

Attributes	Conditions
Temperature (F)	35 to 45
Relative humidity (percent)	< 45
Windspeed (mph)	> 5
Canopy fuel moisture (percent)	< 3

Source: Neuenschwander 1980.

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Mountain Big Sagebrush (Artemisia tridentata ssp. vaseyana)

Mountain big sagebrush (*Artemisia tridentata* Nutt. ssp. *vaseyana* Rybd. (Beetle)) (USDA 2004) is commonly the dominant or codominant shrub in a variety of habitats ranging from montane parklands to warm desert fringes in western North America (Johnson 2000). Mountain big sagebrush is the most common sagebrush in the Great Basin pinyon-juniper woodlands of Nevada (Tueller and others 1979, West and others 1978) and is found throughout large areas in the foothills and mountains of California, northern Arizona, New Mexico, northwestern Colorado, southern and central Idaho, eastern Oregon, Wyoming, western Montana, central Washington, and the southern interior of British Columbia (Blaisdell and others 1982, Harvey 1981, Hickman 1993, McArthur and others 1979, Morris and others 1976, Parish and others 1996, Tisdale 1994). These communities are the most mesic of the big sagebrush communities, commonly occurring on deep fertile soils along the upper elevational range of sagebrush communities (appendices B and C) (Beetle 1960, 1961, Blaisdell and others 1982, McArthur and others 1979, Winward 1980, Tisdale 1994). Communities can often be found growing in a complex mosaic with both basin and Wyoming big sagebrush (Tisdale 1994, Burke 1989, Burke and others 1989a, Burke and others 1989b).

Physiology and Morphology

Mountain big sagebrush commonly grows from 35 to 40 inches tall and appears as flat-topped due to the nearly equal height of flowering stalks (Tisdale 1994, Lackschewitz 1991). It is a long-lived species reaching greater than 50 years old (Beetle and Johnson 1982, Blaisdell and others 1982).

In Utah, (Richards and Caldwell 1987) documented root lengths of 6.5 feet for mature mountain sagebrush in alluvial soils. Mountain sagebrush in greenhouse studies had root lengths of 22.3 feet after 6 months (Welch and Jacobson 1988). Mountain big sagebrush roots are colonized by vesicular-arbuscular mycorrhizae fungi (Caldwell and others 1985, Trent and others 1994).

An Idaho study of sagebrush phenology (Winward and Tisdale 1977) found marked differences in timing and rates of development among big sagebrush taxa. Mountain big sagebrush's initial growth was approximately 2 weeks later than that of basin and Wyoming big sagebrush, however, seed ripening occurred 2 weeks ahead of the other taxa. Seasonal development of mountain big sagebrush in Idaho is presented in table 21. Blaisdell and others (1982) reported some strains of mountain big sagebrush start blooming in early July with seeds maturing from September through October.

Table 21— Phenology of mountain big sagebrush in southern Idaho.

Developmental stage	Date
Early shoot development	Late June
Medium shoot development	Early July
Full shoot development	Mid-July
Flowerheads green	Mid to late July
Flowerheads yellow	Early August
Pollination	Early September
Seeds ripe	Late September

Source: Winward and Tisdale 1977.

Reproduction

Mountain big sagebrush reproduces by seed, although layering has been recorded (Beetle and Johnson 1982, Beetle and Young 1965, Harvey 1981, McArthur and others 1976, Sheehy and Winward 1981). This subspecies does not resprout when aboveground tissues are killed by fire (Blaisdell 1953, Blaisdell and others 1982, Neuenschwander No Date). Seedlings may grow quickly and produce seed within 3 to 5 years (Bunting and others 1987). Seedling emergence is

enhanced under cold, moist conditions and exposure to light (McDonough and Harniss 1974a, McDonough and Harniss 1974b, Meyer and others 1990). Germination response is different between populations of mountain big sagebrush in different habitats (Meyer and Monsen 1991, Meyer and Monsen 1992), however, light is required for germination across all populations (Meyer and others 1990). Significant differences have been recorded between percent germination and climate variables such as light and cold; seed from areas experiencing long cold winters germinating slowly and inconsistently in comparison to seed in areas with short mild winters (Meyer and Monsen 1991, Meyer and Monsen 1992, Meyer and others 1990).

Seed banking and germination response is not clearly defined by the literature. In a western Nevada greenhouse study seeds did not persist in a soil seed bank (Young and Evans 1989). The number of viable seeds decreased sharply throughout the winter months to undetectable levels by the following June. Over a 4 year period, seed reserves were not detected from June to November. While hundreds of seedlings emerged in February all seedlings died by June. No successful seedling establishment was documented in any of the plots over the 4-year study. Harniss and McDonough (1976) did not find any year-to-year variability in average seedling germination, which ranged from 11 to 17 percent. In contrast, Chaplin and Winward (1982) documented relatively rapid post-fire establishment from fire-treated seed in the seedbank.

Ziegenhagen (2004) found significant seed banking for mountain big sagebrush. She found that following fire sagebrush reestablishment occurred in three distinct phases. Phase 1 was an initial flush of seedlings from soil seed pool which lasted 1 to 4 years with the first year showing by far the largest establishment peak. Phase 2 was a lull in seedling establishment that lasts until newly established shrubs reach maturity or until seed from adjacent unburned

communities eventually migrate to the interior of the fire. Sagebrush may produce seeds very quickly (2 to 3 years in good conditions, Daubenmire 1975), but likely in most instances plants do not produce seeds for about 7 years. Phase 3 was marked by the beginning of modal establishment from mature, on-site seed sources. Phase 3 often begins in years with average to above avareage precipitation. Phase 3 would continue until the stand was fully stocked.

The literature on seedling response following fire is unclear. In western Nevada, Young and Evans (1989) investigated an August wildfire in which all standing woody material was removed in a mountain big sagebrush community and found that after the first post-fire growing season, seedling density was 4 per acre. In contrast, Raper and others (1985) found seedling densities of 1,090 per acre on burned plots as compared to 97 seedlings per acre on unburned paired plots in a high elevation mountain big sagebrush community in Wyoming.

Ecological Information

Mountain big sagebrush occupies a broad elevational range from 2,600 feet to 9,840 feet (McArthur and others 1979) and may be found in full sun or the shade of mature conifers (Noste and Bushey 1987, West and others 1978). These communities receive 14 to 18 inches of annual precipitation (Tisdale 1994). Some site characteristics for mountain big sagebrush communities for the Great Basin are presented in table 22.

Table 22—Mountain big sagebrush site characteristics.

Lifeform	Percent composition by weight	Site productivity (lb/ac)	Shrub foliar cover (percent)
Shrubs	25-30	1,000 to 2,500	25-30
Grasses	40-50		
Forbs	25		
Litter	High		

Source: Tisdale 1994.

Mountain big sagebrush is a climax dominant species, which is often associated with forest species such as Douglas-fir (*Pseudotsuga menziesii*), ponderosa pine (*Pinus ponderosa*),

lodgepole pine (*Pinus contorta*), and western juniper (*Juniperus occidentalis*) (Beetle 1961, Beetle and Johnson 1982, Johnson and others 1994). Fire suppression has been a factor in the invasion of mountain big sagebrush communities by juniper woodlands, lodgepole pine, and Douglas-fir (Bunting 1990, Burkhardt and Tisdale 1976, Miller and Rose 1998, Beetle 1961, Arno and Gruell 1983). In southern British Columbia, mountain big sagebrush occupies openings in subalpine fir forest (*Abies lasiocarpa*). Many of these communities are considered edaphic or topographic climax communities (Beetle 1961, Beetle and Johnson 1982, McLean 1970).

Common plant associates in the mountain big sagebrush stands of Idaho and Montana include Wood's rose (*Rosa woodsii*), mountain snowberry (*Symphoricarpos oreophilus*), yellow rabbitbrush (*Chrysothamnus viscidiflorus*), antelope bitterbrush (*Purshia tridentata*), and Rocky Mountain juniper (*Juniperus scopulorum*). Important graminoid associates include bluebunch wheatgrass (*Pseudoroegneria spicata*), Idaho fescue (*Festuca idahoensis*), Kentucky bluegrass (*Poa pratensis*), cheatgrass (*Bromus tectorum*), and prairie Junegrass (*Koeleria macrantha*) (Kaltenecker and Wicklow-Howard 1994, Marlow and others 1987, Monsen and Anderson 1995, Winward 1970). In central and eastern Oregon and Washington associated species, include ponderosa pine, Wyoming big sagebrush, gray low sagebrush (*A. arbuscula* ssp. *arbuscula*), bottlebrush squirreltail (*Elymus elymoides*), Sandberg bluegrass (*Poa secunda*), and basin wildrye (*Leymus cinereus*) (Clark and others 1997, Rose and Eddleman 1994, Vaitkus and Eddleman 1991, Winward 1980). In Wyoming, addition species include needle-and-thread (*Hesperostipa comata*), and spike fescue (*Leucopoa kingii*) (Beetle 1961, Burke 1989, Burke and others 1989). Great Basin associates include pinyon species (*Pinus* spp.), Utah juniper (*Juniperus osteosperma*), Gambel oak (*Quercus gambelii*), black sagebrush (*A. nova*), basin big

sagebrush, and Columbia needlegrass (*Achnatherum nelsonii*) (Tausch and Tueller 1990, Trent and others 1994, TRW Environmental Safety Systems Inc. 1999, Tueller and others 1979, West and others 1978, Young and others 1989).

Soils in mountain big sagebrush communities are characterized by moderately deep, well-drained profile being either slight acidic to alkaline. Snow cover remains into early spring, and provides summer moisture (Beetle 1961, Blaisdell and others 1982, Burke 1989, Burke and others 1989a, McArthur and others 1979, Tueller and Eckert 1987, West and others 1978). Soils in these communities have higher organic matter, nutrients, and microbial biomass than soils in the more exposed Wyoming and basin big sagebrush communities (Burke 1989, Burke and others 1989a, Burke 1989, Burke and others 1989b).

Disturbance Response

Mountain big sagebrush is killed by fire and does not resprout (Bunting and others 1987). Bunting and others (1987) found mountain big sagebrush requires at least 15 years to recover following fire. Depending on environmental and plant conditions, seeds may germinate in abundance following spring burning (Champlin 1982, Raper and others 1985) or sparsely (Blaisdell 1953, Hargis and McCarthy 1986, Kuntz 1982). Regardless, seedlings may grow to reproductive maturity in 3 to 5 years (Bunting and others 1987). Fire often reduces the dominance of mountain big sagebrush and, if exotic species have not invaded the stand, the pre-fire community will be achieved again (Akinsoji 1988, Blaisdell and others 1982, Bunting 1990, Mueggler 1976, Neuenschwander No Date). In a southern Idaho long-term study, Blaisdell (1953), Blaisdell and others (1982), and Harniss and Murray (1973) recorded slower mountain big sagebrush recovery than expected. The study area was free of cheatgrass, and was not grazed the first year following the burn, with only light grazing the following years. Sagebrush was

practically eliminated, and reestablishment was slow the first 9 years, while mountain big sagebrush cover greatly increased after18 years.

Ziegenhagen (2004) found that recovery of mountain big sagebrush following fire was highly variable. The number of years since fire explained from 57% of the sagebrush recovery suggesting other factors also influence post-fire recovery (table 22b and fig. 11). She hypothesized from her study and other studies that sagebrush recovery following fire is highly dependent upon establishment within the first couple of post-fire years which is dependent on available soil moisture, climate, topography, size and intensity of fire, and initial floristics. Her study and those of Harniss and Murray (1973), Barney and Frischknecht (1974), Watts and Wambolt (1996) Nelle and others (2000), and Lesica and others (2005) suggest that sagebrush cover returns to preburn levels in 30 to 36 years. Ziegenhagen (2004) found that incident radiation explained an addition 9% of the variability in percent live sagebrush cover where recovery increased on north aspects. She developed simple linear regression equations showing shrub cover, density and percent composition associated with time since burning (table 22b).

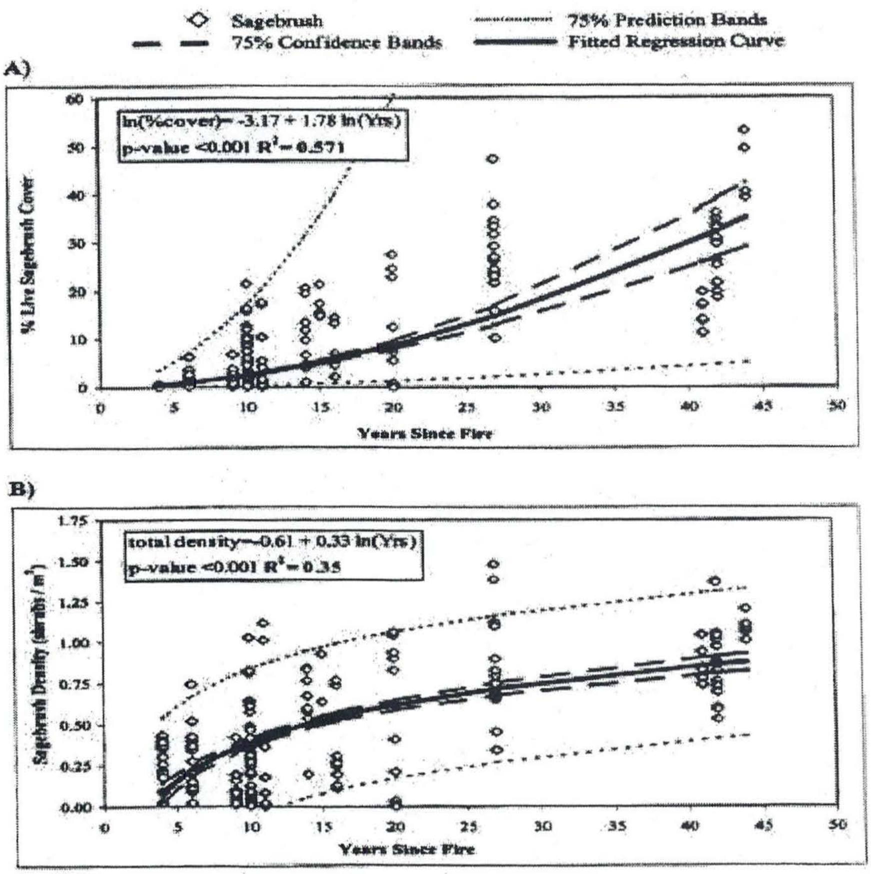
Table 22b. Simple linear regression equations and back-transformed slopes from shrub cover, density, and % composition associated with years since fire.

Regression Equation	P-value	R^2	Back-transformed slopes with 90% Confidence Intervals
ln (Total Shrub % Live Cover) = 0.130 + 0.891 ln (Yrs)	<0.001	0.38	A doubling of years is associated with a 1.85-fold change in the median % live cover of all shrub species. 2^B= 1.854 (2.052 to 1.675)
"Total Shrub" Density= 0.607 + 0.114 ln (Yrs)	0.041	0.02	A doubling of years is associated with a 0.079-unit change in the mean total density of all shrub species. log (2)B1, = 0.079 (0.142 to 0.015)
Sagebrush % Composition= -37.05 + 33.633 ln(Yrs)	<0.001	0.45	A doubling of years is associated with a 2331-unit change in the mean % composition of sagebrush. log (2)B1= 23313 (26.612 to 20.014)
Sagebrush Total Density= 0.618 + 0328 ln(Yrs)	<0.001	0.36	A doubling of years is associated with a 0.23-unit change in the mean total density (shrubs/m2) of sagebrush. log (2)B1= 0.227 (0.267 to 0.188)
ln(Sagebrush % Live Cover) = 3.167 + 1.778 ln(Yrs)	<0.001	0.57	A doubling of years is associated with a 3.43-fold change hi the median % live cover of sagebrush. 2^ B' = 3.429 (3.932 to 2.990)
ln (Rabbitbrush % Composition) = 5.779 + -1.219 ln (Yrs)	<0.001	0.28	A doubling of years is associated with a -0.43-fold change in the median % composition of rabbitbrush. 2^ B' = -0.430 (-0.511 to -0.361)
Ln (Rabbitbrush % Live	0.001	0.07	A doubling of years is associated with a -0.72-fold

Cover) = 1.899 + -0.467 ln (Yrs)			change in the median % live cover of rabbitbrush. 2^B'= -0.724 (-0.840 to -0.624)
ln (Rabbltbrush Total Density) = 0340 + -0.452 In(Yrs)	0.0019	0.06	A doubling of years is associated with a -0.73-fold change in the median total density (shrubs/m2) of rabbitbrush. 2^B'= -0.731 (-0.862 to -0.620)

(Source Ziegenhagen 2004, Table 3.3, p. 28).

Figure 11. Regression equations show cover and density of mountain big sagebrush as related to years since burning (from Ziegenhagen 2004).



Fire return intervals for mountain big sagebrush vary from 15 to 25 years (Burkhardt and Tisdale 1969, Houston 1973, Miller and others 2000). In southwest Idaho evidence showed fires occurred 3 to 5 times per century before 1910 (Burkhardt and Tisdale 1976). Arno and Gruell (1983) hypothesized that fire intervals of 20 years would control sagebrush invasion in grassland communities of Montana.

As a result of fire suppression western juniper has invaded many mountain big sagebrush communities (Burkhardt and Tisdale 1969, Miller and Rose 1995, Miller and others 2000). Overly frequent fires suppress seedling establishment, while fire suppression allows for tree invasion. In addition, sagebrush acts as a nurse plant for juniper seedlings (Miller and Rose 1995). On sites in Oregon and California, Miller and others (2000) recorded mountain big sagebrush declines of 80 percent of maximum potential, with western juniper increasing to 50 percent of maximum cover. Burkhardt and Tisdale (1976) concluded that fire frequencies of 30 to 40 years would control western juniper invasion of sagebrush communities.

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Wyoming Big Sagebrush (Artemisia tridentata ssp. wyomingensis)

Wyoming big sagebrush (*Artemisia tridentata* Nutt. ssp. *wyomingensis* Beetle & Young) (USDA 2004) has the largest distribution of the big sagebrush cover types ranging from southern Oregon and Idaho, into parts of Montana and North Dakota, western Wyoming, and south through Colorado, Utah, Nevada, California, New Mexico, Arizona, and Nebraska (Tisdale 1994, Hickman 1993, Welsh and others 1987). Wyoming big sagebrush occupies areas climatically similar to those supporting basin big sagebrush but moderately shallow soils characterize the climax communities of this xeric species (Tisdale 1994), however, its distribution is poorly defined where it overlaps other big sagebrush subspecies (Weber 1987, Welsh and others 1987). Wyoming big sagebrush hybridizes with other big sagebrush subspecies (Collins and Harper 1982, Freeman and others 1991, McArthur and others 1998) and silver sagebrush (*A. cana*) (McArthur and others 1998).

Physiology and Morphology

Wyoming big sagebrush is the most drought tolerant of the 3 major big sagebrush subspecies (Meyer and Monsen 1993). It typically grows from 18 to 30 inches tall; crowns are rounded and uneven with the main stem branched near ground level into 2 or more substems (Beetle and Johnson 1982, Schlatterer 1973). In Wyoming, Sturges (1977) found this subspecies often lives to 42 years old in undisturbed sites; similarly, Vincent (1992) found plants up to 50 years old in New Mexico. Ferguson (1964) hypothesizes plants may surpass 150 years old (Ferguson 1964).

Development of Wyoming big sagebrush commences in the early spring with the appearance of ephemeral leaves. These leaves are retained until the onset of summer drought. Perennial leaves develop slowly into July, with flowering beginning in late August or September.

Fruits ripen from mid-October to mid-November (Shaw and Monsen 1990, Winward and Tisdale 1977) with most of the seed shed in the fall (Mozingo 1987). The phenology of Wyoming big sagebrush in northern Utah is presented in table 23.

Table 23— Phenology of Wyoming big sagebrush in northern Utah.

Phenology	Month
Root elongation	April to mid-May
Shoot elongation	May to mid-August
Flowering	mid-July to September
Fruiting	mid-August to September

Source: Fernandez and Caldwell 1975.

The root system of Wyoming big sagebrush is well-developed and deep, penetrating as far as 6 feet. The majority of the roots (approximately 35 percent of the total root mass) are found within 1 foot of the soil surface (Fernandez and Caldwell 1975, Leaf 1975, Sturges 1977). Furthermore, the root system contains the vesicular-arbuscular mycorrhizae *Glomus microcarpus* and *Gigaspora* species (Bethlenfalvay and Dakessian 1984, Doerr and others 1971, Hurley and Wicklow-Howard 1986).

Reproduction

Wyoming big sagebrush reproduces from seed and does not sprout or layer (Beetle and Young 1965, McArthur and others 1977, Schlatterer 1973). However, Wyoming big sagebrush/plains silver sagebrush (*A. cana* ssp. *cana*) hybrids often sprout following fire (McArthur and others 1998). Plants are capable of self-pollination but outcrossing is more common (Freeman and others 1991). Moderately sized plants may produce approximately 350,000 seeds a season (Goodwin 1956) starting from 3 or 4 years of age (McArthur and others 1977, Tisdale and others 1969). Seeds shatter within a week of maturation (Goodwin 1956) and generally travel less than 100 feet from the parent plant (Beetle 1960, Tisdale and others 1969).

Following disturbance, Wyoming big sagebrush reestablishes primarily from the seedbank (Hironaka and others 1983).

Germination rates are improved with light exposure, and a short (<4 week) stratification period (Meyer and others 1988, Meyer and Monsen 1992, Mozingo 1987). Laboratory germination rates where high from 50 to 95^0 F (Eddleman 1979, Shaw and Monsen 1990) with 43 to 70 percent germination in 3 years of seed collected from Dubois, Idaho (Harniss and McDonough 1976). Fresh seed collected from 5 western states had 69 to 100 percent germination (Meyer and Monsen 1992). Apparently, fire has no effect on seed germination (Chaplin and Winward 1982).

Wyoming big sagebrush is a slow growing species even when moisture and nutrients are not limiting (Blank and others 1994, Booth and others 1990). In greenhouse trials (Booth and others 1990) found this subspecies stopped growing early in the growing season and was smaller than basin or mountain big sagebrush despite favorable growing conditions. Furthermore, heavy litter inhibits seedling establishment, whereas light litter favors establishment.

Beetle (1960) found drought conditions favor Wyoming big sagebrush seedlings over perennial bunchgrasses (Beetle 1960). Moreover, Wyoming big sagebrush seedlings out-competed mature bluebunch wheatgrass (*Pseudoroegneria spicata*) for water, although crested wheatgrass (*Agropyron cristatum*) and desert wheatgrass (*A. desertorum*) were more competitive.

Ecological Information

This xeric big sagebrush subspecies is found from elevations of 2,500 feet in Idaho (Winward and Tisdale 1977) to over 7,000 feet in California (Hickman 1993). Precipitation in

these communities is from 7 to 12 inches. Some site characteristics for Wyoming big sagebrush communities in the Great Basin communities are presented in table 24 and Wyoming big sagebrush site production by condition class is presented in table 25. These communities occupy foothills, undulating terraces, slopes, and plateaus, and are less commonly found in basins and valley bottoms (Cronquist and others 1994, Dorn 1988, Francis 1983, Hodgkinson 1989, Tiedeman and others 1987). Plants occur on all aspects but are most common on east- and west-facing slopes (Burke and others 1989, Tiedeman and others 1987, Tweit and Houston 1980).

Table 24—Wyoming big sagebrush site characteristics.

Lifeform	Percent composition by weight	Site productivity (lb/ac)	Shrub foliar cover (percent)
Shrubs	25 to 35	400 to 700	13 to 18
Grasses	50 to 60		
Forbs	20		
Litter	Sparse		

Source: Tisdale 1994.

Table 25—Wyoming big sagebrush community productivity.

Community type	Productivity (lb/ac)
Wyoming big sagebrush (Poor condition)	400
Wyoming big sagebrush (Excellent condition)	900

Source: Schlatterer 1973.

Bates (2004) found interannual climate variability has major influences over forage production in the sagebrush steppe ecosystem on the Northern Great Basin Experimental Range in Oregon. Herbaceous productivity was tracked by clipping every 2 weeks for 6 growing seasons (April—August) in burned and unburned sagebrush-grass communities. Burning in the 5.8 acre plot occurred in the late summer of 1997 (the unburned plot was 7.5 acres); grazing was excluded on both plots since 1994.

Peak production differed between the burned and unburned treatments 3 of 6 years (Bates 2004). In burned plots peak perennial grass production agreed with community peak production 83 percent of the time, while in unburned plots perennial peak production matched community

peak production 50 percent of the time. Sandberg's bluegrass and perennial and annual forbs often occurred earlier than peak production of perennial bunchgrasses (Appendix J) (Bates 2004).

Bates (2004) found annual precipitation and community productivity were not consistent. Crop year precipitation accounted for only 72 and 90 percent of the variation in respective unburned and burned perennial forb communities. In the unburned treatment crop year precipitation predicted peak productivity for: perennial grasses 45 percent of the time, Sandberg's bluegrass 51 percent of the time, annual forbs 45 percent of the time, and the whole community 55 percent of the time. Other factors are influencing community and functional group peak productivity. Passey and others (1982) and Sneva (1982) documented weak correlations between crop year precipitation and herbaceous production; while Sneva (1982) and Sneva and Britton (1983) documented strong correlations. Weak correlations could result from underestimation of precipitation as snow, poor characterization of the effect of precipitation timing, and factor interactions such as temperature and soil nitrogen (Bates 2004).

The most common Wyoming big sagebrush community is the Wyoming big sagebrush/bluebunch wheatgrass type (Miller and others 1986). Other codominant species include western wheatgrass (*Pascopyrum smithii*), Sandberg bluegrass (*Poa secunda*), bottlebrush squirreltail (*Elymus elymoides*), Idaho fescue (*Festuca idahoensis*), Thurber needlegrass (*Achnatherum thurberianum*), and needle-and-thread (*Hesperostipa comata*) (Doescher and others 1986, Francis 1983, Hironaka and others 1983, Lentz and Simonson 1987). Cheatgrass is another important species in these communities (Doescher and others 1986). Other associated species include broom snakeweed (*Gutierrezia sarothrae*), yellow rabbitbrush (*Chrysothamnus viscidiflorus*), rubber rabbitbrush (*Ericameria nauseosa*) fourwing saltbrush

(*Artiplex canescens*), black greasewood (*Sarcobatus vermiculatus*), shadscale (*Atriplex confertifolia*), winterfat (*Krascheninnidovia lanata*), and blue grama (*Bouteloua gracilis*) (Hodgkinson 1989, Holland 1986, Johnston 1987, Tiedeman and others 1987, Bunting and others 1993, Heitschmidt and others 1995).

Wyoming big sagebrush is also an important understory dominant in the pinyon-juniper (*Pinus-Juniperus* spp.), and ponderosa pine (*Pinus ponderosa*) communities (Eddleman and others 1994, Rose and Eddleman 1994, Tausch and Tueller 1990, West and others 1998). In northern Arizona, Hodgkinson (1989) documented Wyoming big sagebrush as the most abundant big sagebrush species in the singleleaf pinyon (*P. monophylla*)/Utah juniper (*J. osteosperma*) communities. It is also present in the same communities found in the Great Basin (West and others 1998). Associated species in these forest and woodland types include western juniper (*J. occidentalis*), mountain big sagebrush, low sagebrush (*A. arbuscula*), wax currant (*Ribes cereum*), yellow rabbitbrush, common snowberry (*Symphoricarpos albus*), and Saskatoon serviceberry (*Amelanchier alnifolia*) (Rose and Eddleman 1994).

Davies and others (2004) identified five community associations in southeastern Oregon after sampling 107 Wyoming big sagebrush communities in high ecological condition (table 26). Annual grass cover was mainly composed of cheatgrass and generally had very low cover. Herbaceous and shrub cover was extremely variable across all sites. Wyoming big sagebrush cover was only significantly higher in the bluebunch wheatgrass-Thurber's needlegrass sites ($p < 0.05$).

Table 26—Wyoming big sagebrush association characteristics in southeastern Oregon.

Association	Wyoming big sagebrush cover (percent)	Perennial grass cover (percent)	Annual grass cover (percent)
Wyoming big sagebrush/bluebunch wheatgrass	12.0±0.48	11.9±0.46	0.8±0.22
Wyoming big sagebrush/Thurber's needlegrass	13.5±0.91	8.8±0.36	0.4±0.24

Wyoming big sagebrush/Idaho fescue	9.9±2.28	11.0±1.97	0.8±0.22
Wyoming big sagebrush/needle-and-thread	11.1±0.90	19.4±1.20	0.02±0.01
Wyoming big sagebrush/bluebunch wheatgrass-Thurber's fescue	16.8±2.44	9.4±0.88	0.7±0.27

Source: Davies and others 2003.

Wyoming big sagebrush is found across a broad range of soil types including frigid, mesic, and xeric soils with textures ranging from silty, clayey, skeletal, and mixtures (Francis 1983, Hodgkinson 1989, Holland 1986, Passey and others 1982, Winward 1983). Parent material in these communities is high variable (Tweit and Houston 1980) with soil pH ranging from moderately acidic to moderately basic (Holland 1986, Johnston 1987). In areas where there is overlap of the three major big sagebrush subspecies, Wyoming big sagebrush tends toward the shallowest, most well-drained, and hottest soils. In contrast, mountain big sagebrush occupies moderately deep soils that are wetter and deeper than those of Wyoming big sagebrush. Basin big sagebrush occupies the most fertile and deepest soils (Barker and McKell 1983, Bonham and others 1991, Winward 1983). In Wyoming, on sites were Wyoming big sagebrush intermixes with black (*A. nova*), low, and threetip (*A. tripartita*) sagebrush, dwarf sagebrushes occupy the shallower soils (Tweit and Houston 1980).

Disturbance Response

Fire kills Wyoming big sagebrush (Bunting and others 1987, Bushey 1987, Cluff and others 1983, Eichhorn and Watts 1984, Fischer and others 1996, Neuenschwander 1980, Peek and others 1979, Wambolt and Payne 1986, Wright and others 1979). Site reestablishment is the result of soil stored seed (Beetle and Young 1965, McArthur and others 1977, Schlatterer 1973), and seed from remnant and off-site plants (Bushey 1987, Clifton 1981).

Wyoming big sagebrush recovery occurs more slowly than the other subspecies (Clifton 1981, Peek and others 1979, West and Hassan 1985, Young and Evans 1978). Bushey (1987) concluded that seed from remnant plants is the principle means of site colonization following fire due to the mosaics created by non-continuous burning. Depending on site conditions, generally a decade or more is required for plants to reestablish following fire (Sturges 1994). In Montana, Eichhorn and Watts (1984) did not find seedling recruitment in a former Wyoming big sagebrush/bluebunch wheatgrass site 14 years after burning. Similarly, Wambolt and Payne (1986) found less than 2 percent canopy cover of Wyoming big sagebrush 18 years after burning. Blaisdell and others (1982) noted the effective use of fire could reduce cover for 25 to 50 years.

The fire interval for this subspecies is from 10 to 70 years (Britton and others 1981, Bunting and others 1987, Frandsen 1983, Harniss and Murray 1973, Hironaka 1991, Kaltenecker and Wicklow-Howard 1994, Peek and others 1979, Vincent 1992, West and Hassan 1985, Young and others 1979, Young and Evans 1981, Young and others 1976) and is the primary means of renewal for decadent stands (Blank and others 1994). However, in California, Young and Evans (1981) documented a fire interval from 10 to 40 years and from 40 to 50 years in New Mexico (Vincent 1992, Young and others 1979).

Bates and others (2004) assessed the first and second year post-wildfire recovery of Wyoming big sagebrush alliance in southeastern Oregon. Seven pre- fire plots were established in an area where over 16,000 ha burned in the Sheepshead range in August 2001 as the result of a wildfire. The study plots represented Wyoming big sagebrush/bluebunch wheatgrass and Wyoming big sagebrush Thurber's needlegrass associations in mid to high seral ecological condition. The wildfire was intense removing Wyoming big sagebrush from all plots. Bareground increased significantly while cover of herbaceous vegetation, litter, moss, and crust

declined significantly. Thurber's needlegrass and Sandberg's bluegrass responded slowly the first two years following the fire. Cheatgrass has increased slowly in these areas. Bluebunch wheatgrass recovered more quickly than Thurber's needlegrass and Sandberg's bluegrass and as a result cheatgrass is a minor component on these sites.

Vegetation response to wildfire varied by species. Mat forming and dense bunchgrasses were the most severely impacted whereas species such as bluebunch wheatgrass and bottle brush squirreltail with reduced basal biomass where only slightly damaged (table 27). In addition, forbs with growing points belowground were unaffected or increased following the fire (table 27). The high mortality of mat forming and dense bunchgrasses in the presence of cheatgrass suggests substantial risk of conversion of these sites following intense wildfire (Bates and others 2004).

Table 27—Plant species response following wildfire in Wyoming big sagebrush/Thurber's needlegrass and Wyoming big sagebrush/bluebunch wheatgrass associations in the Sheepshead Mountains, Oregon (from Bates and others 2004).

	Grasses	
Severely impacted[1]	**Slightly impacted**	**No impact or enhanced**
Thurber's needlegrass, Idaho fescue, Cusick's bluegrass, Sandberg's bluegrass	bluebunch wheatgrass, bottlebrush sqiurreltail, Sandberg's bluegrass,	cheatgrass, six weeks fescue
	Perennial Forbs	
Severely impacted	**Slightly impacted**	**No impact or enhanced**
low pussytoes, Hood's phlox, obscure milkvetch, dwarf yellow fleabane, scabland fleabane, desert yellow fleabane, oval-leaved. Eriogonum, Hook's daisy,	velvet lupine, daggerpod, lava aster, wooly-pod milkvetch, morning milkvetch	speckle pod milkvetch, Brunea mariposa lily, basalt milkvetch, low hawksbeard, taper-tip hawksbeard, western hawksbeard, big seed lomatium, broadsheath lomatium, Nevada lomatium, taper-tip onion, long-leaved phlox, one-stemmed groundsel, Bolander's yampah,
	Annual forbs	
Severely impacted	**Slightly impacted**	**No impact or enhanced**
None	white daisy tidytips	desert alyssum, little blue-eyed Mary, cushion cyrptantha, autumn willow-weed, groundsmoke spp, sinuate gilia, white-stemmed blazing star, thread-stem linanthus, pink microsteris, thread-leaf phacelia, burr buttercup, Jim Hill tumble mustard, pinnate tansy mustard, yellow salsify

[1] Severely impacted - species cover reduced by more than 80%o with no change in cover in years following fire. Slightly impacted - species cover between 50 to 90% of pre burn levels the first 2 years after fire.

impact or enhanced - Cover not affected 01 increased above pre-burn levels.

Wyoming big sagebrush is a mid- to late-seral species (Eddleman and Doescher 1978, Francis 1983, Sturges 1994), which, in the absence of fire for >50 years may lose dominance on sites (Kindschy 1994). In Oregon, long established perennial herbs dominated sites with old dead and decadent Wyoming big sagebrush (Kindschy 1994). Principal component analysis of Wyoming big sagebrush steppe communities produced the successional model presented in table 28.

Table 28—Successional model of Wyoming big sagebrush steppe community of Wyoming.

Seral stage	Dominant vegetation
Early	Forbs
Early intermediate	Blue grama
Late intermediate	Western wheatgrass
Late	Wyoming big sagebrush

Source: Benkobi and Uresk, 1996.

Prescribed burning of Wyoming big sagebrush sites might be difficult due to low fuel loads but with the right combination of wind, and temperature these sites can burn (Winward 1983). Characteristics of a prescribed fire in Nevada are presented in table 29.

Table 29—Prescribed fire characteristics of a Wyoming big sagebrush site in Nevada.

Attributes	Condition
Temperature (F)	70
Relative humidity (percent)	15
Windspeed (mph)	1 to 3
Fuel moisture (percent)	3
Live sagebrush moisture (percent)	93
Soil moisture (percent)	8

Source: Bushey 1987.

Several modeling approaches have been taken to estimate fire behavior and the probability of burning in Wyoming big sagebrush types. Brown (1982) has developed a model to captur e fuels and fire behavior in Wyoming and mountain big sagebrush communities. Britton and other (Britton and others 1981) established canopy cover-herbaceous fuel load curves

to predict burn success, and Frandsen (1983) developed a model estimating fuel loading and fire behavior in these types.

Cheatgrass has radically altered fire regimes in Wyoming big sagebrush communities (Bunting and others 1987, Hironaka 1991, Kaltenecker and Wicklow-Howard 1994, McArthur and others 1998, Shaw and Monsen 1990, Tisdale and others 1969). Cheatgrass is common in frequently disturbed sites (Evenden 1989) and is found as the dominant understory species in many communities throughout southern Idaho, northern Nevada, and eastern Oregon. Annual cheatgrass production can be considerable with favorable precipitation and can enhance the probability of fire spread (Bunting and others 1987). Some cheatgrass communities have burned 2 or 3 times within 10 years (Boltz 1994). Repeated burning and invasion by cheatgrass removes Wyoming big sagebrush and inhibits its reestablishment (Rose and Eddleman 1994). As a result, some Wyoming big sagebrush steppe sites have converted to annual grasslands (Monsen and Kitchen 1994). Artificial seeding of native grasses is recommended if cheatgrass is a major component of the post-fire community (West and Hassan 1985, Young and others 1976).

Prescribed burning of Wyoming big sagebrush communities with 50 percent cheatgrass canopy cover or less than 20 percent native grasses is not recommended because cheatgrass is likely to invade the site if the dominant grass is not fire-resistant or the native community is in poor condition (Pechanec and others 1954, West and Hassan 1985). Cheatgrass is more likely to invade drier regions such as those found in southern Idaho, eastern Oregon, and northern Nevada and Utah (Hironaka and others 1983). Communities in good condition benefit from favorable precipitation following burning despite temporary post-fire increases in cheatgrass (West and Hassan 1985). Furthermore, a gradual reduction in Wyoming big sagebrush cover is recommended to maintain the vigor and seed production of native perennials (Hironaka and

others 1983). Changes in Wyoming big sagebrush, bluebunch wheatgrass, and cheatgrass following a wildfire in central Utah are presented in table 30.

Table 30—Changes in dominant species canopy cover follow wildfire in central Utah.

Dominant species	Mean canopy cover (percent)					
	Prefire		Postfire year 1		Postfire year 2	
	Burn Site	Control	Burn Site	Control	Burn Site	Control
Wyoming big sagebrush	6.5	2.3	0	3.7	0	5.7
Bluebunch wheatgrass	12.9	13.3	6.5	16.0	12.3	13.3
Cheatgrass	6.6	6.8	34.8	11.0	56.8	24.0

Source: West and Hassan 1985.

In Idaho, Clifton (1981) burned a Wyoming big sagebrush/bluebunch wheatgrass community to improve sage grouse habitat. Bare ground constituted 47 percent of the site with 36 percent litter cover. The fire prescription and actual conditions for the burn are presented in table 31. Ten to 15 percent of the area burned, significantly reducing Wyoming big sagebrush in those areas.

Table 31—Fire prescription versus actual burn results for wildfire in central Utah.

Attributes	Conditions	
	Prescribed	Actual
Fine fuel moisture (percent)	13 to 30	No Available
Relative humidity (percent)	20 to 45	19 to 36
Windspeed (mph)	5 to 30	3 to 25
Temperature (F)	50 to 85	64 to 85

Source: Clifton 1981.

Wyoming big sagebrush is preferred browse for pronghorn and other wild ungulates (Allen and other 1984, Bray and others 1991, Peek and others 1979, Shaw and Monsen 1990, Welch and McArthur 1986). In addition, these communities are a critical source of food and cover for sage grouse (Autenrieth and others 1982, Clifton 1981, Fischer and others 1993, Fischer and others 1996, Tweit and Houston 1980, Welch and others 1991). However, cattle and sheep use in these types is negligible (Ngugi and others 1992, Sheehy and Winward 1981, Riggs and Urness 1989). Wyoming big sagebrush may increase under heavy grazing (Schlatterer 1973, Tweit and Houston 1980), however, in southern Idaho Anderson and Holte (1981) found it

decreased after 50 years of grazing pressure. Significant increases in canopy cover were documented with the removal of livestock.

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Dwarf Sagebrush Species

The Dwarf sagebrush species are those that are generally small shrubs with height mostly below 16 inches. The Dwarf sagebrush species discussed are low sagebrush (*A. arbuscula*), Bigelow sagebrush (*Artemisia bigelovii*), Low Sagebrush (*Artemisia arbuscula*), Black sagebrush (*Artemisia nova*), Stiff sagebrush (*Artemisia rigida*), and Bud sagebrush (*Picrothamnus desertorum*). These sagebrush species dominate on shallow soils or areas with lowered productivity as compared to the "tall" sage species. In general, these community types often act as fire breaks under natural conditions.

Low sagebrush (Artemisia arbuscula Nutt.)

Low sagebrush (*Artemisia arbuscula* Nutt.) (USDA 2004) has four recognized subspecies (table 32) and is found across 39,100 square miles of the western United States from southern Colorado to western Montana and west through the Great Basin to northern California, Oregon, and Washington (Kartesz and Meacham 1999). A low sagebrush type typically occurs on harsh, dry, rocky sites (Winward 1980). In the Great Basin these types are found on slopes and ridgetops of hilly and mountainous terrain (Zamora and Tueller 1973), and the coldest, driest woodland sites (Mozingo 1987); they are considered a topoedaphic climax species in dry sagebrush-grassland communities with shallow, rocky soils. These sites are generally drier and rockier than sites supporting big sagebrush (*Artemisia tridentata*) communities (McArthur and Stevens 1986).

Table 32—Low sagebrush subspecies.

Scientific name	Common name
Artemisia arbuscula Nutt. *ssp. Arbuscula*	Gray low sagebrush
Artemisia arbuscula Nutt. *ssp. longicaulis* Winward & McArthur	Lahontan sagebrush
Artemisia arbuscula Nutt. *ssp. longiloba* (Osterhout) L. Shultz	Alkali sagebrush
Artemisia arbuscula Nutt. *ssp. termopola* Beetle	Hotsprings sagebrush

Source: USDA 2004, Steinberg 2002.

Physiology and Morphology

Low sagebrush is a drought tolerant (Mozingo 1987) species reaching 150 years-old (Mooney 1985). Subspecies exhibit a variety of heights (table 33). Gray low sagebrush, alkali sagebrush, and hotsprings sagebrush are dwarf sagebrushes (Hickman 1993, Hitchcock and Cronquist 1973). All subspecies are many-branched and have a mounded form (Hickman 1993). Lahontan sagebrush has more erect flower stalks than gray low sagebrush (Winward and others 1986).

Table 33—Low sagebrush subspecies growth characteristics.

Subspecies	height (inches)	Rooting depth (inches)
Gray low sagebrush	4 to 16	
Alkali sagebrush	4 to16	8
Lahontan sagebrush	12 to 36	
Hotsprings sagebrush	6 to 9	

Source: Hickman 1993, Hitchcock and Cronquist 1973, Winward and others 1986, Beetle 1977.

Roots of low sagebrush are extensive, fibrous, and generally are tolerant of poor aeration. They are more efficient at transporting water from this soil depth than either big or black sagebrush (Mozingo 1987, West 1969).

New growth of low sagebrush starts in May with flower heads developing in July; by October seeds are beginning to ripen (McArthur and Stevens 1986, Shaw and Monsen 1990). Alkali sagebrush has earlier development than the other subspecies, with growth beginning in May, and seed ripening occurring in July and August (Beetle 1960, McArthur and others 1979, Schlatterer 1973). Early season growth is that of the terminal bud, however, as soil moisture declines auxiliary growth dominates (West 1969).

In southwestern Idaho, Wight and others (1986) measured evapotranspiration, using a lysimeter, in a low sagebrush (*Artemisia arbuscula*)/sandberg's bluegrass (*Poa secunda*)-bottlebrush squirreltail (*Sitanion hystrix*) from 1977 to 1979 (table 34). The lysimeter was

installed in 1968, however the data presented for 1977, 1978, and 1979 represents low, above average, and average production years, respectively (Wight and others 1986).

Table 34—Evapotranspiration, beginning soil moisture, and monthly precipitation for a low sagebrush community in southwestern Idaho (from Wight and others 1986).

Year	Attribute	Month (mm/day)						Beginning soil water[1] (mm)
		April	May	June	July	August	September	
1977	Lysimeter	No data	1.98	2.67	1.59	0.96	1.14	18
	Precipitation(mm/month)	2	63	47	10	15	14	
1978	Lysimeter	2.40	1.77	2.53	1.15	0.88	1.11	119
	Precipitation (mm/month)	84	18	17	12	12	22	
1979	Lysimeter	1.35	2.45	2.41	0.69	1.25	0.55	129
	Precipitation (mm/month)	20	28	11	5	49	2	

[1] Amount of available plant soil water in the root zone at the beginning of the growing season (approximately April 1).

Reproduction

Low sagebrush reproduces primarily by seed and does not resprout (Beetle 1960, McArthur and others 1979, McArthur and Stevens 1986, Shaw and Monsen 1990, Ward 1953). Seed crops are large, frequent, and wind-dispersed (Young 1983). Seed viability is approximately 4 to 6 years in dry storage (Shaw and Monsen 1990). No information is available on seed banking. Germination of low sagebrush requires warm temperatures followed by a cold treatment. In nursery trials Vories (1981) found 10-day chilling at 36^0 F was successful, with the highest germination rates occurring from 73^0 to 86^0 F with seeds planted 0.25 inch deep in fall or winter on shallow clayey soils with sun exposure. Mortality is high the first year of growth (Shaw and Monsen 1990).

Layering occurs infrequently (McArthur and others 1979, McArthur and Stevens 1986, Shaw and Monsen 1990, Ward 1953). Alkali sagebrush layers more frequently than other subspecies (Beetle and Johnson 1982).

Ecological Information

The broad elevational range of low sagebrush extends from 3,000 feet to over 12,000 feet, and overlaps with that of big sagebrush and black sagebrush (*Artemisia nova*) (Blaisdell and others 1982, McArthur and Stevens 1986). Sites receive 7 to 18 inches of precipitation (Stevens 1983). Beetle (1960) documented low sagebrush in early seral big sagebrush communities and along stream bottoms. Important shrubs in this type include yellow rabbitbrush (*Chrysothamnus viscidiflorus*), slender eriogonum (*Eriogonum microthecum*), and- on some sites- antelope bitterbrush (*Purshia tridentata*) (Volland 1985, Dealy and others 1981, Hopkins 1979). Important graminoids include bluebunch wheatgrass (*Pseudoroegneria spicata*), Idaho fescue (*Festuca idahoensis*), and Sandburg bluegrass (*Poa secunda*). Other associated grasses include bottlebrush squirreltail (*Elymus elymoides*), Thurber needlegrass (*Achnatherum therberinum*), needle-and-thread (*Hesperostipa comata*), and prairie junegrass (*Koeleria macrantha*). Generally low sagebrush communities lack deep-rooted perennial bunchgrasses (Hironaka and others 1983) or competitive native annuals (Young and Evans 1970). Cheatgrass (*Bromus tectorum*) is also an important grass in this type. Some of the more common forbs include wild onion (*Allium* spp.), pussytoes (*Antennaria dimorpha*), and balsamroot species (*Balsamorhiza hookeri* and *B. sagittata*), among other species (Tisdale 1994).

These stands are especially susceptible to invasion by medusahead (*Taeniatherum caput-medusae*) (Young and Evans 1971, Young and others 1984). It is thought that early successional stages in this type are more susceptible to invasion (Tirmenstein 1988). Communities with high shrub cover are somewhat resistant to medusahead invasion (Young and Evans 1970 and 1971). Some general site characteristics for low sagebrush sites are presented in table 35.

Table 35—Low sagebrush site characteristics.

Lifeform	Composition by weight (%)	Site productivity (lb/ac)	Average canopy cover (%)
Shrubs	35	300 to 650 620 to 800[1]	15 to 25
Grasses	45		
Forbs	20		
Ground cover			
Litter	30		
Gravel	50		
Bare ground	50		

Source: Tisdale 1994.

[1] Nettleton and others 1986.

Soils are mostly shallow and infertile with an impermeable claypan layer or bedrock substrate 8 to 13 inches from the surface (Barbour and Major 1977, Fosberg and Hironaka 1964, Hickman 1993, Hironaka and others 1983, Sheehy and Winward 1981). The shallow soils inhibit the growth of big sagebrush (Beetle and Johnson 1982). Many low sagebrush sites have low moisture holding capacity resulting in summer drought. In the spring a perched water table, the result of the claypan, may cause spring flooding (Beetle and Johnson 1982, Young and Evans 1971). Deeper soils have 30 percent or more gravel and cobbles in the horizon (Beetle and Johnson 1982). This cover type grows well on noncalcareous, alkaline soils (Beetle and Johnson 1982, Blaisdell and others 1982) and is also found on glacial tills, dolomite, sandstone, and granitic soils (West 1969) with highly eroded surface soils in some areas (Young and others 1984).

Disturbance Response

Post-disturbance recovery of low sagebrush communities depends largely on site characteristics and plant associates. Young (1983) and Bradley and others (1992) found low sagebrush may reoccupy a site in 2 to 5 years. However, on harsh sites where erosion occurs after fire it may take up to 10 years for recovery (Blaisdell and others 1982, Young 1983). On

high potential low sagebrush sites perennial bunchgrasses, such as Idaho fescue (*Festuca idahoensis*), bluebunch wheatgrass (*Pseudoroegneria spicata*), and Thurber's fescue (*Festuca thurberi*) rapidly establish, generally require 2 to 4 years to recover from disturbance (Eckert and others 1972, Wright and others 1979). Long-term changes in low sagebrush communities following fire are not well-documented (Tirmenstein 1988).

Fire intervals were thought to be relatively long (Beetle and Johnson 1982, Blaisdell and others 1982) due to the lack of fine fuels to carry a fire (Blaisdell and others 1982, Gipe 1976, Young 1983) and wide shrub spacing (Britton and Ralphs 1979, Bunting and others 1987, Clifton 1981, Neuenschwander 1978, Paysen and others 2000, Young 1983). Fire intervals from several studies are presented in table 36. In addition, the likelihood of fire increases in communities with large amounts of weedy species such as cheatgrass (*Bromus tectorum*) and medusahead, or during years with above-average precipitation (Blaisdell and others 1982, Hironaka and others 1983, Bunting and others 1987).

Table 36—Fire intervals and fuel loads for low sagebrush types.

Community	Fire interval (years)	Fuel load[4] (lb/ac)
Idaho big sagebrush/low sagebrush mosaic[1]	4	100 to 400 600 (max.)
Oregon site[2]	12 to 15	
California low sagebrush/ western juniper[3]	10 to 90	

[1] Burkhardt and Tisdale 1976.
[2] Miller and Rose 1999.
[3] Young and Evans 1981.
[4] Lewis 1971, Schlatterer 1972.

Burning in Utah conducted in September with a relative humidity of 15 to 20 percent, temperature of 75^0 F, and 5 to 10 mile per hour winds, and fuel loading of 100 lbs/ac. "essentially eliminated" low sagebrush (Ralphs and Busby 1979). However, low sagebrush communities have been used as fuel breaks (Bunting and others 1987, Young 1983). Dean and others (1981) have fine fuel equations for low sagebrush.

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Bigelow Sagebrush (Artemisia bigelovii)

Bigelow sagebrush (*Artemisia bigelovii* Gray) (USDA 2004) is a dwarf sagebrush (Beetle 1960, Belnap and others 2001) commonly found throughout 34,010 mi^2 of the arid southwestern deserts (McArthur and others 1979, McArthur and Stevens 1986). The xeric four corners region of the Colorado Plateau is the center of its distribution (Johnson 1987, McArthur and Stevens 1986, West 1979), from which it radiates into northern Arizona, southeastern California, southern Nevada, central Utah, south-central New Mexico, and the Texas panhandle (Great Plains Flora Association 1986, Kartesz and Meacham 1999, Kartesz 1988, Kearney and others 1960, Martin and Hutchins 1981, Welsh and others 1987). In Colorado Bigelow sagebrush is limited to areas near the Arkansas River valley (Harrington 1964, Weber and Wittmann 1996). This desert sagebrush is found in all successional seres from open early successional communities to relic, ungrazed communities (Pendleton and others 1989, Schmutz and others 1967).

Physiology and Morphology

Bigelow sagebrush is typically from 12 to 16 inches tall (Beetle 1960, Hickman 1993, Martin and Hutchins 1981) and has rounded, multiple, recurved stems. The bark is shreddy with leaves from 0.6 to 1.0 inch long and 0.08 to 0.16 inch wide (Great Plains Flora Association 1986, Kartesz and Meacham 1999). The inflorescence is a dense panicle with 2 to 7 flowers per flowerhead (Great Plains Flora Association 1986, Martin and Hutchins 1981). The flowers of Bigelow sagebrush are unique in that they have 1 to 3 pistillate ray flowers (Johnson 1987, Tisdale and Hironaka 1981

Bigelow sagebrush's spring growth begins in April with flower buds appearing in August and flowering continuing to October (Beetle 1960, Kearney and others 1960, McArthur and Stevens 1986).

Reproduction

Bigelow sagebrush reproduces from seed alone (Beetle 1960, Tisdale and Hironaka 1981, Wright and others 1979) and is wind pollinated (Pendleton and others 1989). Seed production, germination, and distribution are poorly understood (Howard 2003).

Ecological Information

Bigelow sagebrush is found from elevations of 3,000 to 8,000 feet on xeric sites with well drained, sandy or gravelly, limestone soils (Hickman 1993, Johnson 1987, Kartesz 1988, McArthur 1994, McGinnies and others 1991). As the most drought-tolerant sagebrush (Beetle 1960, Johnson 1987, McArthur and Stevens 1986, Tisdale and Hironaka 1981), it is commonly found in canyons or draws, and washes, plains, hills, and rimrock (Hickman 1993, Kartesz 1988, Martin and Hutchins 1981, Welsh and others 1987).

Bigelow sagebrush sites include Colorado pinyon-oneseed juniper (*Pinus edulis-Juniperus monosperma*) singleleaf pinyon (*P. monophylla*), and desert shrub communities of the Sonora, Great Basin, and Mojave deserts (Bunting 1998, Jameson and others 1962, Kearney and others 1960, McArthur and others 1977, McArthur and Stevens 1986, Ribble and Samson 1987, Welsh and others 1987). These desert communities, while having relatively high soil crust cover (Belnap and others 2001), include species such as big sagebrush (*A. tridentata*), black sagebrush (*A. nova*), blackbrush (*Coleogyne ramosissima*), saltbrush (*Artiplex* spp.), and broom snakeweed (*Gutierrezia sarothrae*) (Kartesz 1988, McArthur and others 1977, McArthur and Stevens 1986,

McGinnies and others 1991). In the desert shrub-grassland communities of northern Arizona and New Mexico important species include big sagebrush, yellow rabbitbrush (*Chrysothamnus viscidiflorus*), green ephedra (*Ephedra viridis*), fourwing saltbush (*A.canescens*), galleta (*Pleuraphis jamesii*), and blue grama (*Bouteloua gracilis*).

In the Great Basin associated species include fourwing saltbush, Fremont barberry (*Mahonia fremontii*), blue grama, ring muhly (*Muhlenbergia torreyana*), and bottlebrush squirreltail (*Elymus elymoides*) are important (Rosenstock and Van Riper 2001). Bigelow sagebrush/broom snakeweed communities give way to blue grama/buffalo grass (*Buchloe dactyloides*) communities along the eastern edge of Bigelow sagebrush's distribution (McGinnies and others 1991). On the southern Colorado steppe important associates include yucca (*Yucca glauca*), pale wolfberry (*Lycium pallidum*), winterfat (*Krascheninnikovia lanata*), and tree cholla (*Opuntia imbricata*). Shortgrass prairie species often include blue grama, black grama (*B. eriopoda*), western wheatgrass (*Pascopyrum smithii*), and galleta (Shaw and Diersing 1990).

Disturbance Response

The successional role of Bigelow sagebrush is unclear (Howard 2003). Pendleton and others (1989) documented Bigelow sagebrush in open stands and suggest it may be favored in early successional communities. In Arizona, Schmutz and others (1967) found Bigelow sagebrush on sites with a history of heavy sheep and cattle grazing, however it was also found in relict, ungrazed communities.

Fire kills Bigelow sagebrush (McArthur 1981), however there are no published studies on its response to fire. Because Bigelow sagebrush relies on off-site, wind-dispersed seed, post-fire

establishment may follow that of big sagebrush (Howard 2003); taking 15 to 20 years to regain cover on mesic sites and 50 to 75 years on xeric sites (Blaisdell and others 1982, Bunting and others 1987).

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Silver Sagebrush (Artemisia cana)

Silver sagebrush (*Artemisia cana* Pursh) (USDA 2004) has three recognized subspecies (table 37) and is one of the most common sagebrush species, second only to big sagebrush (*A.* tridentata). Silver sagebrush occupying over 53,221 mi^2 of the western United States (Beetle 1960, Beetle 1977). It is commonly found in the northern Great Plains, Rocky Mountains, and Intermountain regions (Winward 2001), but it is uncommon in the Great Basin (Mozingo 1987), rare in Utah, and absent from Washington (Cronquist and others 1994, Kartesz and Meacham 1999). Silver sagebrush occurs throughout all successional stages (Beetle 1960, Knapp 1991, Padgett and others 1989, Rosentreter 1992).

Table 37—Silver sagebrush subspecies (from USDA 2004, Howard 2002).

Scientific name	Common name
Artemisia cana Pursh ssp. *cana*	Plains silver sagebrush
Artemisia cana Pursh ssp. *bolanderi* (Gray) G.H. Ward	Bolander silver sagebrush
Artemisia cana Pursh ssp. *viscidula* (Osterhout) Beetle	Mountain silver sagebrush

The subspecies Bolander silver sagebrush (*A. cana* ssp. *bolanderi*) populations are disjunct from the other subspecies, occurring from north-central Oregon (Crawford and Kagan 2001), along the eastern slope of the Cascade Range, south to the eastern edge of the Great Basin, and in portions of California and Nevada (CalFlora 2000, Harvey 1981, Kartesz and Meacham 1999, McArthur 1994, Mozingo 1987).

Plains silver sagebrush (*A. cana* ssp. *cana*) is common east of the Continental Divide, occurring in southern British Columbia, southwestern Manitoba, eastern Colorado, central Wyoming, and south-central Montana (Harvey 1981, Kartesz and Meacham 1999, Weber and Wittmann 1996). Distribution of plains and mountain (*A. cana* ssp. *viscidula*) overlap in eastern Idaho, western Montana, throughout Wyoming, and in north-central Colorado (Harvey 1981).

Mountain silver sagebrush is the most common subspecies west of the Continental Divide; occurring throughout central Idaho, western Montana, central Colorado, northeastern New Mexico, north-central Arizona, central Nevada, and eastern Oregon (Harvey 1981, Kartesz and Meacham 1999, McArthur 1994, Mozingo 1987, Weber and Wittmann 1996).

Physiology and Morphology

Silver sagebrush is a moisture tolerant (Schultz and McAdoo 2002, Thatcher 1959), rhizomatous (Beetle 1960, Blaisdell and others 1982) species with subspecies exhibiting a variety of heights (table 38). This native shrub has semi-woody to woody stems (Kartesz and Meacham 1999) which are densely branched (Stephens 1973).

Table 38—Silver sagebrush subspecies growth characteristics.

Subspecies	Height (feet)	Rooting depth[1] (feet)
Plains silver sagebrush	3 to 4	
Bolander silver sagebrush	<3.0	7 to 10
Mountain silver sagebrush	1.0	

Source: Great Plains Flora Association 1986, Hickman 1993, Beetle 1960.
[1] Coupland and Johnson 1965.

Seedling growth begins from March to June depending on latitude and elevation (Beetle 1960, Harvey 1981, Hou and Romo 1998, Romo and Grilz 2002). In southern Montana, Harvey (1981) found established plants initiated growth in late March with flowering occurring in mid-August to early September and seed dissemination starting in mid-September to mid-October. Generally, seed dissemination is a long process in which some fruits remain until winter or spring. Romo and Young (2002) found some seedlings didn't emerge until mid-April or mid-June. In the Great Basin, northern Great Plains, and interior Pacific Northwest flowering occurs from August to September (Cronquist and others 1994, Eddleman 1977, Great Plains Flora Association 1986, Kartesz 1988, McArthur and Stevens 1986, Mozingo 1987), in California and

Oregon it occurs in July and August (Hayes and Garrison 1960, Hickman 1993), and from July through September in New Mexico (Martin and Hutchins 1981).

Silver sagebrush is tolerant of flooding when compared to other woody sagebrush species (Schultz and McAdoo 2002); however, its drought tolerance is uncertain. Mature plants have been documented as both drought intolerant (McArthur 1994) and tolerant (Ellison and Woolfolk 1937, Gutknecht 1989). In an anecdotal study across the Great Plains, post-drought survival of silver sagebrush was comparable to big sagebrush with silver sagebrush showing greater seedling establishment (Ellison and Woolfolk 1937, Reed and Peterson 1961), however, seedlings are sensitive to water stress (Walton 1984, Wambolt and others 1989).

Reproduction

Silver sagebrush reproduces from seed, sprouting, and layering (Harvey 1981, Walton 1984). Pollen is generally spread by wind, this coupled with large population sizes tend to minimize between-population differences (McArthur and others 1998). Seed production begins in plants 4 years old (Romo and Grilz 2002). Despite high seed production and germination rates, seedling establishment is low (Valles and McArthur 2001).

Silver sagebrush seed is capable of immediate germination with or without light; however, higher germination rates are achieved when seeds remain on the parent plant through cold temperatures (Vories 1981, Eddleman 1977, Walton 1984). Greenhouse trials found 93 percent germination at 68^0 F and 97 percent germination at 59^0 F (Harvey 1981). In Montana, Harvey (1981) found seeds lost viability when exposed to 86^0 F temperatures for 14 days prior to planting. Furthermore, laboratory tests conducted by Eddleman (1977) had 73 percent germination from stratified, year-old seed as compared to 26 percent germination from

unstratified two month-old seed. In Saskatchewan, Romo and Young (2002) found plains silver sagebrush lost viability rapidly when exposed to field environments, however, spring-sown seed showed significantly better emergence than fall-sown seeds. Romo and Young (2002) suggest silver sagebrush may have a small seed bank reserve on certain sites.

Despite the high germination rates and prolific seed production of silver sagebrush few plants survive the seedling stage (Walton and others 1986). In southern Montana, Harvey (1981) found that 3.4 percent of seedlings survived their first year. In Saskatchewan, Romo and Grilz (2002) found only 6 percent of planted seed became established seedlings, but of those surviving the first year 85 percent also survived the second year. Drought is the primary cause of seedling mortality. Walton (1984) and Wambolt and others (1989) recorded pulses of seedling establishment in years of above-average precipitation. Moreover, Harvey (1981) and Romo and Grilz (2002) determined that seedlings require open ground that is free from competition, which is rare in undisturbed to lightly disturbed mature stands (Hazlett and Hoffman 1975).

Silver sagebrush is the strongest sprouter in its subgenus (Harvey 1981, Walton 1984, Wright and others 1979) and commonly reproduces through cloning (Romo and Young, 2002, Wambolt and others 1989). Silver sagebrush has the ability to layer (Beetle 1960, Harvey 1981, Hayes and Garrison 1960, Johnson 1979, Wasser 1982), and sprout from its roots (Beetle 1960, Beetle and Johnson 1982, Blaisdell and others 1982, Cronquist and others 1994, Harvey 1981, Hayes and Garrison 1960, McArthur and others 1979, Mozingo 1987), rhizomes (Beetle 1960, Blaisdell and others 1982, McArthur and others 1979, Mozingo 1987, Schultz and McAdoo 2002, Stubbendieck and others 1992, Wasser 1982), and the root crown (Ellison and Woolfolk 1937, Rupp and others 1997, Wasser 1982a). On disturbed sites both seedlings and sprouts may be present, however, on undisturbed sites sprouting and layering is the nearly the sole method of

reproduction. Seedlings originating from seed outnumbered those from rhizomes on very gravelly and very clayey sites (Harvey 1981, Wambolt and others 1989). In a pruning study, plants annually pruned to 0.5 feet responded with "vigorous" sprouting from the root crown (Rupp and others 1997). While in Montana, Wambolt and others (1989) found plains silver sagebrush rhizomes averaged 3.4 feet with 1 to 52 sprouts, on plants averaging 1.0 foot tall. Average parent rhizomes were 8 years-old.

Ecological Information

Silver sagebrush species range in elevation from 5,000 to nearly 11,000 feet (Blaisdell and others 1982, Schultz and McAdoo 2002, Winward 2001). Along this elevational gradient the various subspecies of silver sagebrush exhibit unique ecological site characteristics (table 39).

Table 39—Silver sagebrush subspecies characteristics.

Subspecies	Precipitation (inches)	Canopy cover	Site characteristics
plains silver sagebrush[1]	12 to 15	High	Mesic to moist uplands and lowlands
mountain silver sagebrush[2]	15 to 25	High	Higher elevation, cool, riparian/upland sagebrush ecotone
Bolander silver sagebrush[3]	6 to 8	Sparse	Internally drained, high desert basins

[1] Hansen and others 1984, Johnson 1987, Wasser 1982, Thatcher 1959, Ellison and Woolfolk 1937, Hazlett and Hoffman 1975, Ralston 1960.
[2] Wasser 1982, Johnston 1987, Youngblood and others 1985.
[3] Wasser 1982, Hironaka and others 1983, Winward 1980, Beetle 1960.

Plains silver sagebrush dominates the shrub layer with western snowberry (*Symphoricarpos occidentalis*) and fringed sagebrush (*A. frigida*) as the only shrub associates (Nelson 1961). Western wheatgrass (*Pascopyrum smithii*) is the most common grass in good-condition bottomlands. Other predominant grasses include green needlegrass (*Nassella viridula*), thickspike wheatgrass (*Elymus macrourus*), and slender wheatgrass (*E. trachycaulus*). Secondary grasses include needle-and-thread (*Hesperostipa comata*), blue grama (*Bouteloua

gracilis), prairie junegrass (*Koeleria macrantha*), and plains reedgrass (*Calamovilfa longifolia*) (McMurray 1988a). Western snowberry and slender wheatgrass increase on sites with above-average moisture conditions, while blue grama and green needlegrass become more important on drier sites (Nelson 1961, Coupland 1965, Hanson and Whitman 1938).

Mountain silver sagebrush upland communities are dominated by mountain big sagebrush (*A. tridentata* ssp. *vaseyana*), while adjacent riparian communities are dominated by shrubby cinquefoil (*Dasiphora floribunda*), and willow (*Salix* spp.) (Youngblood and others 1985). On these sites mountain silver sagebrush often represents a topographic climax (Terwilliger and Tiedeman 1978). Silver sagebrush/Idaho fescue understory dominated sites often occur at mid to upper elevation sites, while Thurber's fescue (*Festuca thurberi*) sites are found in colder areas bordering the subalpine zone (Johnson 1987, Terwilliger and Tiedeman 1978, Wasser and Hess 1982b). Other important graminoids include California brome (*Bromus carinatus*), sedge species (*Carex* spp.), slender wheatgrass, rush species (*Juncus* spp.), Sandberg bluegrass (*Poa secunda*), and Kentucky bluegrass (*Poa pratensis*). Common forbs include western yarrow (*Achillea millefolium*), aster (*Aster* spp.), wild strawberry (*Frageria virginiana*), Douglas knotweed (*Polygonum douglasii*), showy cinquefoil (*Potentilla gracilis*), and dandelion (*Taraxacum officinale*) (McMurray, 1988b).

In Bolander silver sagebrush types of western Idaho and southeastern Oregon mat muhly (*Muhlenbergia richardsonis*) is the climax dominant. Sandberg bluegrass is an important associate on Oregon sites (Hironaka and others 1983). Other important grasses include Baltic rush (*Juncus balticus*), Douglas' sedge (*Carex douglasii*), bottlebrush squirreltail (*Elymus elymoides*), and spikerush (*Eleocharis* spp.). Important forbs include Newberry cinquefoil (*Potentilla newberryi*), Fremont's combleaf (*Polyctemium fremontii*), tiny mousetail (*Myosurus*

minimus), and showy downingia (*Downingia elegans*) (Dealy and others 1981, Hironaka and others 1983).

Silver sagebrush is generally the only shrub present, while grasses dominate the understory of this cover type (Hansen and others 1984, Reed 1952, Schlatterer 1972, Youngblood and others 1985). Bare ground and soil crusts are generally low in undisturbed silver sagebrush communities (Belnap and others 2001, Padgett 1981). In climax stands silver sagebrush may form nearly closed stands (Hanson and Whitman 1938, Winward 2001). Ground cover for a study of mountain silver sagebrush in Oregon is presented in table 40.

Table 40—Mountain silver sagebrush ground cover.

Cover type		Percent cover
Undisturbed site	Bare ground	<3
Disturbed site	Bare ground	17

Source: Padgett 1981.

Plains silver sagebrush generally occupies areas with a water table within 3 feet of the soil surface (Schultz and McAdoo 2002, Thatcher 1959); preferring colder, moister sites than any other woody sagebrush species (West 1988). These sites are found primarily in drainages, alluvial flats, and valley-bottom terraces (Hansen and others 1984, Ellison and Woolfolk 1937, Hazlett and Hoffman 1975, Ralston 1960, Thatcher 1959); all of which are subject to periodic erosion, deposition, and flooding (Nelson 1961, Walton and others 1986, Johnson 1979). Soil drainage is often slow and phosphorus, potassium, nitrogen, organic matter, and cation exchange capacity are lower than in adjacent communities. Silver sagebrush has no tolerance for strongly saline or calcareous soils (Hazlett and Hoffman 1975, Schultz and McAdoo 2002, Walton and others 1986) and is found within a pH range of 6.0 to 8.5 (Brichta 1986, Hansen and others 1994, Hansen and others 1995, Thatcher 1959). Parent material includes sandstone, shales, and granites (Olson and Gerhart 1982) with the best growth occuring on alluvial soils that are moist

in the upper 6 inches of the profile, well drained, and coarse-textured (Hansen and others 1994, Walton and others 1986).

Soil descriptions for mountain and Bolander silver sagebrush are incomplete, however, Youngblood and others (1985) suggest many mountain silver sagebrush sites, are subirrigated from adjacent upland sites. Whereas, Bolander silver sagebrush soils are clayey with high alkaline content (Cornelius and Talbolt 1955) and commonly experience temporary spring flooding (Dealy and others 1981).

Disturbance Response

Silver sagebrush occurs in early to late successional stages (Beetle 1960, Knapp 1991, Padgett and others 1989, Romo and Young 2002); preferring open sites with light shade (Wasser 1982). In Montana, a riparian stand on the Yellowstone River started as a bare sandbar, progressed to a plains cottonwood /sandbar willow (*Populus deltoides/Salix exigua*) gallery, next to a Wood's rose/western snowberry (*Rosa woodsii/Symphoricarpos occidentalis*) shrubland, and finally on to a climax silver sagebrush/western wheatgrass-prairie sandreed steppe (Boggs 1984, Boggs and Weaver 1992, Hansen and others 1990). Hansen and others (1990) hypothesize this is a grazing disclimax community. In the Badlands of North Dakota, Nelson (1961) documented the invasion of a plains cottonwood gallery by silver sagebrush directly without a Wood's rose/western snowberry stage. In a Wyoming study, Reed (1952) documented silver sagebrush invasion of hayfields, some of which later converted to quaking aspen (*Populus tremuloides*) stands. Silver sagebrush has been documented invading overgrazed mountain meadows (Ream 1964). In Utah, Padgett and others (1989) noted that with the removal of heavy grazing, mountain rangelands returned to stable silver sagebrush/bunchgrass communities. In Alberta,

Erichsen-Arychuk and others (2002) documented increased plains silver sagebrush following wildfire, grazing, and three successive years of drought. The western wheatgrass/blue grama grassland was in excellent condition prior to the wildfire.

Sprouting from roots and rhizomes is the primary means of post-fire regeneration for silver sagebrush (Britton 1979, Cronquist and others 1994, Wright and Bailey 1982, Wright and others 1979, Beetle 1977, McArthur and Stevens 1986, Walton 1984, Wambolt and others 1989). Post-fire regeneration may also include the establishment of seedlings if moisture conditions are favorable (Wambolt and others 1989). Given the rapid growth of sprouting stems (Rupp and others 1997) it is thought that within 2 to 3 years post-fire sprouts will produce seed (Howard 2002). Silver sagebrush can regain or exceed pre-fire canopy cover in 4 to 6 years (Winward 2001).

Fuel loads in these communities is often higher than in surrounding communities due to heavier litter and vertical fuel loads (Padgett 1981, Thilenius and others 1995, Walton 1984). Some mountain silver sagebrush sites are capable of producing up to 2000 lbs./acre total biomass (Winward 2004). Fuel loads for plains silver sagebrush communities in Montana are presented in table 41.

Table 41—Fuel loads for plains silver sagebrush communities.

Community type	Fuel load (lb/ac)
Plains silver sagebrush/blue grama	268
Plains silver sagebrush/western wheatgrass	893

Source: White and Currie 1983.

Fire carries well and spreads through these sites unless overgrazing has altered the community (Blaisdell and others 1982, Walton 1984). As a result, these communities experience stand-replacing fire (Beetle and Johnson 1982, Pechanec and others 1965, White and Currie 1983); the removal of litter encourages sprouting and expansion in silver sagebrush communities

(Walton and others 1986, Wambolt and others 1989). However, fall burns in dry conditions result in higher mortality than spring burns when the plants are not under water stress (McArthur and Stevens 1986, White and Currie 1983).

Fire return intervals for silver sagebrush subspecies is presented in table 42. Fire return intervals of 5 to 20 years favors silver sagebrush (Blaisdell and others 1982, Wambolt and others 1989), while more frequent fire intervals tends to favor bunchgrasses (Kovalchik 1987).

Table 42—Silver sagebrush subspecies fire intervals.

Subspecies	Fire interval (years)
Plains silver sagebrush	5 to 10[1] (rolling plains) 20 to 30[2] (disjunct plains) 16 to 47[3] (relic stands)
Mountain silver sagebrush	25[4] (Snake River plains) 3 to 45[5] (Unknown)
Bolander silver sagebrush	N/A

[1] Wright and Bailey 1982.
[2] Wright and Bailey 1982, Brown and Sieg 1996, Fisher and others 1986, Wendtland and Dodd 1992.
[3] Quinnild and Cosby 1958.
[4] Houston 1973.
[5] Arno 1980, Arno 2000, Heyerdahl and others 1994.

A study by White and Currie (1983) on the seasonal effects of prescribed fire on silver sagebrush in Montana found that silver sagebrush mortality was dependent on fire severity and burning season. Spring burns were conducted in mid-April as plants were breaking dormancy and fall burns were conducted in early October following summer drought, as plants were preparing for seed dispersal. Fuel loading and weather conditions were similar for both treatments; temperatures averaged 70^0 F with winds less than 5 mi/hr. Spring fire killed approximately 1/3 of the completely burned plants. Mortality was less than 10 percent for plants without complete top-kill. Fall burns killed approximately 3/4 of top-killed plants. Plants without complete top-kill suffered 40 percent mortality. Seasonal differences were highly

significant ($p<0.01$). Pre-fire plant size was not significant ($p<0.05$) for fire survival or regrowth. See table 43 for a summary of the results (Howard 2002).

Table 43—Seasonal effects of prescribed fire on silver sagebrush in Montana[1] (from Howard 2002).

Fire severity	Growth characteristics		
	Number of sprouts	Height (mm)	Canopy index (mm)
Spring fire			
foliage consumed	4.5	322	394
twigs & foliage consumed	3.8	305	424
top-killed	3.3	216	358
Fall fire			
foliage consumed	10.3	188	341
twigs & foliage consumed	13.3	188	279
top-killed	4.2	56	96

[1]Mean growth in relation to fire severity. Measurements were made in July 1977 or 1980, after plants had passed through one spring growing season.

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Fringed Sagebrush (Artemisia frigida)

Fringed sagebrush (*Artemisia frigida* Willd.) (USDA 2004) occurs naturally from Alaska south along the Rocky Mountains into New Mexico (Harvey 1981). It also extends into the Great Plains of Colorado, central Nebraska, western Minnesota, central Saskatchewan and Alberta (Hall 1923, Harvey 1981). Fringed sagebrush is often the dominant or codominant species on dry, well-drained soil types characterized by disturbance (McWilliams 2003).

Physiology and Morphology

Fringed sagebrush is a low growing, mat-forming, "semi-shrub." It is both drought and salt tolerant and reaches 14 inches tall with branching woody stems (Institute for Land Rehabilitation 1979). Both ray and disk flowers are present in the numerous, small flowerheads which are borne on nodding racemes or open panicles (McArthur and others 1979). Taproots of this species can reach depths of 5.3 feet (Coupland and Johnson 1965).

In Canada, new growth begins in mid-April with flowering occurring in early August and seeds riping in mid to late September (Coupland 1950). Similarly, in Colorado, Dickinson and Dodd (1976) recorded growth commencing in early April with flowers developing by mid-July and seeds ripening in early September. In the same study, dry fall conditions delayed flowering on some plants and brought on earlier seed dispersal in others.

Reproduction

Fringed sagebrush reproduces by seed (Coupland 1950), and under favorable conditions, by layering (USDA Forest Service 1937). Less than half of fringed sagebrush plants produce seed, even under favorable conditions (Coupland 1950). Three years is required for plants to

produce seed under dry conditions (Wasser 1982). In Saskatchewan, Bai and Romo (1997) determined disturbance does not influence seed production, and control group plants produced from 4,500 to 38,700 seeds per plant. In a study of fringed sagebrush seed dispersal, Iverson (1986) estimated seed traveled 55 inches when dropped from 11.8 inches with 18.6 mi/hr winds.

Fringed sagebrush seeds remain viable for many years (Cooperrider and Bailey 1986, Bai and Romo 1997). In North Dakota, on a mine reclamation site, seeds germinated after 3 to 4 years in the seed bank (Iverson and Wali 1982). Under laboratory conditions, the highest germination rates were achieved with surface planting (Harvey 1981) at 63^0 F over 5.4 days (Sabo and others 1979). No light requirement (Sabo and others 1979) or treatment (McArthur and others 1979) were necessary and germination can occur in any season. However, the majority of seedlings emerge in late spring and early summer due to favorable moisture conditions (Bai and Romo 1996).

Fringed sagebrush's ability to resprout is not well documented. The USDA Forest Service (1937) documented fringed sagebrush layering under favorable conditions and in the mixed-prairie of North Dakota, Whisenant and Uresk (No Date) reported 38 percent of plants resprouted following prescribed fire. In contrast, Bailey (1978) and Peek and others (1985) documented fire kill and severe damage of fringed sagebrush. Continued research is required to determine if these are ecotypic differences.

Ecological Information

Fringed sagebrush occurs over a wide range of habitat and community types from elevations of 4,000 to 11,000 feet in areas that receive from 8 to 12 inches of precipitation. Plants are typically found in full light, on dry, coarse, shallow soils (USDA Forest Service 1937).

In Nevada, plants may also occur in shallow depressions that collect summer precipitation (McArthur and others 1979).

In Colorado, Komarkova (1986) documented 4 fringed sagebrush dominated habitat types; the majority of these occur on warm, dry, south-facing slopes. Moir and Trlica (1976) describe a blue grama (*Bouteloua gracilis*)/fringed sagebrush type. In Rocky Mountain National Park, Allen and others (1991) found fringed sagebrush is the dominant shrub in the ponderosa pine (*Pinus ponderosa*)/fringed sagebrush/needle-and-thread (*Hesperostipa comata*) community type. In Jasper National Park, Nadeau and Corns (2002) describe a prairie Junegrass (*Koeleria macrantha*)/fringed sagebrush/blue flax (*Linum lewisii*) and thickspike wildrye (*Elymus macrourus*) vegetation types. In the Yukon a fringed sagebrush/glaucous bluegrass (*Poa glauca*) community is an edaphic climax type (Douglas 1974).

Common associated species, not yet mentioned, in fringed sagebrush communities are winter fat (*Krascheninnikovia lanata*) (Dormaar and others 1994), shadscale (*Artiplex confertifolia*) (McArthur and others 1979), fourwing saltbush (*A. canescens*) (Klipple and Costello 1960), western wheatgrass (*Pascopyrum smithii*) (Dormaar and others 1994), bluebunch wheatgrass (*Pseudoroegneria spicata*) (Edwards and Armbruster 1989), buffalo grass (*Buchloe dactyloides*) (Ellis and Travis 1975, Klipple and Costello 1960), threadleaf sedge (*Carex filifolia*), saltgrass (*Distichlis spicata*) (Klipple and Costello 1960), broom snakeweed (*Gutierrezia sarothrae*) (Sabo and others 1979), Hood's phlox (*Phlox hoodii*) (Vogel and Van Dyne 1966), and rubber rabbitbrush (*Ericameria nauseosa*) (Klipple and Costello 1960).

Fringed sagebrush occupies all successional niches. It is often referred to as a pioneer or early seral species (Johnson 1987, Rosentreter and Jorgensen 1986, Stark 1966). In the northern mixed prairie it is found throughout all successional stages (Bai and Romo 1996). Furthermore,

Coupland (1992) stated fringed sagebrush was the most abundant half-shrub in climax communities of the mixed-grass prairie. In Idaho, it was found as a pioneer species on harsh sites (Rosentreter and Jorgensen 1986); while in the sand hills of North Dakota it was considered a seral transition species (Burgess 1965).

Fringed sagebrush soil types and growth class is presented in table 44. Soil pH can range from neutral to slightly alkaline (Institute for Land Rehabilitation 1979) on calcareous parent materials (Hann 1982).

Table 44—Fringed sagebrush soil type and growth characteristics.

Growth	Soil type
Good	loam, sandy loam, clay loam
Fair	gravel, sand
Fair to Poor	clay
Poor	dense clay

Source: Dittberner and Olson 1983.

Disturbance Response

Fire top-kills fringed sagebrush and in South Dakota and British Columbia, either eliminated or greatly reduced fringed sagebrush cover (Whisenant and Uresk No Date, Peek and others 1985). Wright and Thompson (1978) and Bailey and Anderson (1978) documented damage to fringed sagebrush plants following both spring and fall burns. In Alberta, following 24 years of annual spring burning in aspen (*Populus tremuloides*) parklands, fringed sagebrush increased in both canopy cover and frequency (Anderson and Bailey 1980). Where resprouting or layering occurs, recovery may take 3 years (Wasser 1982). Cawker (1983) reported that seral fringed sagebrush communities in British Columbia may be favored by frequent fire. No specific studies regarding fire frequencies have been identified (McWilliams 2003).

Fringed sagebrush increases with livestock grazing (Coupland 1950, Lewis and others 1956). In the Northern Great Plains, Rosentreter and Jorgensen (1986) documented a rapid

increase in fringed sagebrush the first 10 years after heavy grazing, with canopy cover decreasing the following 15 years. Fringed sagebrush populations were similar to lightly grazed areas after 25 years.

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Black Sagebrush (Artemisia nova)

Black sagebrush (*Artemisia nova* A. Nels) (USDA 2004) is considered a climax species occupying approximately 43,000 mi^2 and is found primarily throughout the Great Basin (Beetle 1960, McMurray 1986). In addition, scattered populations are located in California, Arizona, and Oregon (Beetle 1960, Beetle and Young 1965, Winward 1980). This climax species often occupies shallow soils along the lower slopes of high desert foothills (McMurray 1986).

Physiology and Morphology

Black sagebrush is a low growing, spreading, native shrub that reaches heights from 6 to 18 inches (McArthur and others 1979). Plants are often decumbent with branches rising from a spreading base. Visible leaf glands distinguish black sagebrush from similar species such as low sagebrush (*A. arbuscula*) (Brunner 1972).

Beetle (1960) described the seasonal growth of black sagebrush in Wyoming. Initial growth begins in late April with new leaves forming in May. Flowering commences in September with seed dispersal following in October. Average phenologic stages recorded by Kleinman (1976) are presented in table 45. Precipitation and soil moisture fluctuations play a significant role in the phenology of black sagebrush (Kleinman 1976).

Table 45—Black sagebrush phenologic development in Wyoming (from Kleinman 1964).

Developmental stage	Date
Growth initiation	May 20
Full bloom	September 15
Seed dissemination	November 5

The root system is adapted to capture surface moisture, being shallower and more fibrous than big sagebrush (Kleinman 1976). Root reserves gradually increased until floral bud

development in August and declined dramatically until September. Twigs are more important in carbohydrate storage than the crown of this species (Coyne and Cook 1970).

Reproduction

Black sagebrush reproduces almost solely by seed. Layering was reported by McArthur and Stevens (1986); however it is quite rare (McMurray 1986). Annual seed production is dependent on site conditions and as such may be highly variable (Beetle 1960). Seeds require mineral soil to germinate; however, no dormancy period is necessary. Seeds retain viability for up to two years under proper conditions (Stevens and McArthur 1974). However, once established, plants on favorable sites in Utah produced seed within 4 years (Wasser 1982).

Ecological Information

Black sagebrush is found from elevations of 4,900 feet to 7,000 feet in areas receiving between 7 and 18 inches of annual precipitation. This climax species occupies dry, well-drained areas including alluvial fans, fills, desert foothills, mountain slopes, and wind swept ridges (McMurray 1986). Shrub associates include basin big sagebrush (*A. tridentata* ssp. *tridentata*), Wyoming big sagebrush (*A. tridentata* ssp. *wyomingensis*), and green ephedra (*Ephedra viridis*). Important graminoids are bottlebrush squirreltail (*Elymus elymoides*), Idaho fescue (*Festuca idahoensis*), Indian ricegrass (*Achnatherum hymenoides*), Sandberg bluegrass (*Poa secunda*), bluebunch wheatgrass (*Pseudoroegneria spicata*), needle-and-thread (*Hesperostipa comata*), and Thurber needlegrass (*A. thurberianum*). Important forbs include phlox species (*Phlox* spp.), northwest Indian paintbrush (*Castilleja angustifolia*), and plains prickly pear (*Opuntia polycantha*) (McMurray 1988). Black sagebrush is also found as a dominant forest understory

species in ponderosa pine (*Pinus ponderosa*), juniper (*Juniperus* spp.), and pinyon (*Pinus edulis*)-juniper types (Alexander 1985).

In areas where low sagebrush (*A. arbuscula*) and black sagebrush are intermixed, black sagebrush occupies the warmer, more xeric and calcareous sites. Mesic sites with deeper soils support basin big sagebrush and Wyoming big sagebrush. Black sagebrush sites are often contiguous with salt desert vegetation in the southern Great Basin (Blaisdell and Holmgren 1984, Blackburn and Tueller 1970, McArthur and others 1979). Many of these low productivity sites have a high proportion of bare ground with black sagebrush covering only 20 percent of the area (Winward 1980). In Oregon, Bunting and others (1987) documented average canopy cover of 12 percent.

Black sagebrush communities have been subject to cheatgrass (*Bromus tectorum*) invasion, however, not to the extent found throughout big sagebrush communities (Hironaka and others 1983). This has increased fire frequency in some stands that otherwise would not burn. Communities with contiguous heavy cheatgrass are particularly vulnerable to fire (Boltz and others 1987).

Disturbance Response

The low productivity and sparse cover of these sites may act as a natural firebreak, which led Winward (1985) to state that historically fire has had little or no influence on these communities. If black sagebrush burns it is killed and relies on off site seed sources (Tisdale and Hironaka 1981, Wright and others 1979, Young 1983). In Utah, West and Hassan (1985) found no evidence of black sagebrush recovery 2 years after a July burn.

Historic winter grazing has degraded black sagebrush communities in the west (Clary 1986). Black sagebrush declines under heavy grazing; however, it increases under moderate and light grazing pressure (Wasser 1982, Hutchings and Stewart 1953).

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Pygmy Sagebrush (Artemisia pygmaea)

Pygmy sagebrush (*Artemisia pygmaea* Gray) (USDA 2004) is generally uncommon but may be locally abundant on xeric sites, covering 5,000 ha (McArthur and others 1979) of the southwestern United States. This species occurs from northern Arizona into the Great Basin and Uinta Basin of Utah and Colorado (Shultz 1986). Hybrids of this species do not exist (Beetle 1960). This xeric, desert species has not been described as an indicator of climax communities (Tirmenstein 1987).

Physiology and Morphology

Pygmy sagebrush is a dwarf, cushionlike, half-shrub reaching up to 8 inches tall (Beetle 1960, McArthur and others 1979). Leaves are pinnately divided into 3 to 11 lobes (Ward 1953) with flowerheads three to five toothed and arranged in a spikelike inflorescence (Beetle 1960, McArthur and others 1979). Ray flowers are lacking (McArthur and others 1979).

Pygmy sagebrush flowers in August and September. Seeds mature in October (McArthur and others 1979). Although documentation on the seasonal development of pygmy sagebrush is sparse, it may be similar to that of black sagebrush (*A. nova*) and bud sagebrush (*Picrothamnus desertorum*) that are found on the same sites.

Reproduction

Pygmy sagebrush does not resprout following disturbance (Beetle 1960, Walton and others 1986), reproducing solely from seed (McArthur and others 1979). Information regarding seed dispersal, germination, and seedling establishment is lacking (Tirmenstein 1987).

Ecological Information

Pygmy sagebrush is found from elevations of 4,000 to 6,000 feet (Johnson 1987) in desert grasslands, pinyon (*Pinus* spp.)-juniper (*Juniperus* spp.) stands, and salt desert communities. Black and bud sagebrush dominate more mesic, less saline, salt desert communities that include pygmy sagebrush (West 1979). In the Great and Uinta basins, pygmy sagebrush is found on calcareous desert soils (Beetle 1960, McArthur 1983). It has also been reported on shale barrens at lower elevations (Shultz 1986) and gypsum outcrops in Nevada (Brunner 1972). Pygmy sagebrush is found in some pinyon-juniper and black sagebrush communities of Utah (Goodrich and Neese 1986, McArthur and others 1979). Optimal soil depth for pygmy sagebrush is from 10 to 20 inches (Dittberner and Olson 1983).

Disturbance Response

Pygmy sagebrush is killed by fire and does not resprout (Beetle 1960, Walton and others 1986). However, it does readily reseed following disturbance (Beetle 1960). Information regarding successional roles, fuel loading, and fire intervals is lacking; however, as it is generally found on some of the more xeric sites with low plant cover natural fire frequencies were likely very low.

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Stiff Sagebrush (Artemisia rigida)

Stiff sagebrush (*Artemisia rigida* (Nutt.) Gray) (USDA 2004) has a highly restricted distribution due to edaphic factors (Tisdale 1994). As a result, this species is limited to shallow soils with underlying basalt found in Washington, northeastern Oregon, and west-central Idaho (Daubenmire 1970, McArthur 1994, Tisdale and Hironaka 1981, Ward 1953). This climax dominant (Anderson and Scherzinger 1975, Rickard 1960) occupies harsh unproductive sites (Johnson 1987).

Physiology and Morphology

Stiff sagebrush is a low and spreading perennial shrub with a conspicuously woody base. Short, rigid branches reach up to 16 inches long, while flowering stems may reach 12 inches in length. Leaves are .4 to 1.6 inches long with 3 conspicuous linear lobes (Beetle 1960, McArthur and others 1979, Ward 1953). The roots are concentrated in rock fractures with 80 percent of the root mass concentrated in the first 2 to 9 inches of soil (Johnson and Simon 1987).

Seasonal development begins in June with flowerheads developing in late July and August, flowering and seed ripening in October through November (Beetle 1960, Blaisdell and others 1982, McArthur and others 1979).

Reproduction

Stiff sagebrush does not resprout or layer; reproduction is solely by seed (Blaisdell and others 1982, McArthur and others 1979, Ward 1953). Specific information about the reproduction of stiff sagebrush is not available.

Ecological Information

Stiff sagebrush sites are often harsh and unproductive (Johnson 1987). Elevations range from 700 to 7,000 feet (Tisdale 1994, Miller and Eddleman 2000, Winward 1980) with precipitation from 8 to 16 inches in the Great Basin (Tisdale 1994, Miller and Eddleman 2000) and 12 to 20 inches in southern Idaho (Hironaka and others 1983). While precipitation is adequate to support larger sagebrush species, the soils are usually less then 10 inches deep or have 50 percent stone or gravel in the profile, thereby limiting site potential to dwarf sagebrush species (Tisdale 1994). Soil depth on sites in Washington and Idaho averages from 4 to 9 inches (Johnson and Simon 1987). These sites are characterized by severe moisture saturation in winter and frost heaving (Hall 1973, Hironaka and others 1983). These soil types have low moisture holding capacity, thus drying out early in the spring (Tisdale 1994). Because distribution of stiff sagebrush is edaphically determined, it often grows in contact with other sagebrush species, especially mountain big sagebrush (*A. tridentata* ssp. *vaseyana*) (Tisdale 1994).

Site characteristics of some stiff sagebrush communities of the Great Basin are presented in table 46. These are the least productive sagebrush cover type in the Great Basin (Tisdale 1994).

Table 46—Stiff sagebrush site characteristics (from Tisdale 1994).

Lifeform	Percent composition by weight	Site productivity (lb/ac)	Shrub foliar cover (percent)
shrubs	35 to 45		
grasses	35 to45		
forbs	15 to 20		
		100 to 200	20
Ground cover			
litter	10 to 15		
bare ground	65		

Stiff sagebrush is the climax dominant species where it occurs (Johnson 1987, Anderson and Scherzinger 1975, Rickard 1960, Culver 1964). Associated species in this region include

Sandberg bluegrass, biscuitroots (*Lomatium* spp.), and cheatgrass (*Bromus tectorum*) (Winward 1980). In Oregon, Hall (1978) lists western juniper (*Juniperus occidentalis*), onespike oatgrass (*Danthonia unispicata*), and bighead clover (*Trifolium macrocephalum*) as common associates in plant communities in good range condition. Hall (1978) goes on to state that cheatgrass and western yarrow (*Achillea millefolium*) are absent on poor condition communities due to site limitations. In Idaho, Hironaka and others (1983) describe a stiff sagebrush/Sandberg bluegrass habitat type occurring on shallow, basalt-derived soils. Species included in this type are bottlebrush squirreltail (*Elymus elymoides*), crested wheatgrass (*Agropyron cristatum*), cheatgrass, and medusahead (*Taeniatherum caput-medusae*) among others.

Disturbance Response

Stiff sagebrush is killed by fire (Daubenmire 1992) and is slow to recolonize burned areas (Agee 1994). There is no literature regarding fire intervals in these communities. However, due to the depauperate nature of the sites, fire in these types is rare (Agee 1994, Bunting and others 1987, Tisdale and Hironaka 1981, Humphrey 1974). Bunting and others (1987) states that these communities may be used as natural fire breaks, however, in years of above average production and/or where annual grasses have invaded fire might carry through these communities.

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Threetip sagebrush (Artemisia tripartita)

Threetip sagebrush (*Artemisia tripartita* Rydb.) (USDA 2004) has two recognized subspecies (table 47) (Beetle 1960, Kartesz 1994). Beetle (1960) documented a threetip sagebrush - mountain silver sagebrush (*A. cana* ssp. *viscidula*) hybrid. In addition, threetip sagebrush may hybridize with Wyoming big sagebrush (*A. tridentata* ssp. *wyomingensis*) (Schlatterer 1973) and low sagebrush (*A. arbuscula* ssp. *arbuscula*) (Beetle 1960). The remainder of this section will refer to threetip sagebrush in general unless specifically stated.

Table 47—Threetip sagebrush subspecies.

Scientific name	Common name
Artemisia tripartita (Rydb.) ssp. *tripartite*	Tall threetip sagebrush
Artemisia tripartita (Rydb.) ssp. *rupicola* Beetle	Wyoming threetip sagebrush

Source: USDA 2004.

This climax species occupies approximately 8.4 million acres across the Rocky Mountains and Great Basin (Bork and others 1998), although Intermountain communities are sparse due to site conversion to farmland (Shultz 1986). Threetip sagebrush grows on steep, rocky knolls and ridges with shallow soils (Beetle and Johnson 1982, Carson and Peek 1987), whereas tall threetip sagebrush is found along rivers and drainages (Beetle and Johnson 1982). Wyoming threetip sagebrush is also found in shallow soils, and on barren knolls surrounded by grasslands (Beetle 1960). Threetip sagebrush's range extends from British Columbia, south through central Washington and western Oregon into eastern Idaho, western Montana, the Snake River Valley of Wyoming, and northern Utah. Wyoming threetip sagebrush occurs on the east-side of the Continental Divide in Wyoming and throughout southern Oregon (Beetle 1960, Beetle and Johnson 1982, Brunner 1972).

Physiology and Morphology

Tall threetip sagebrush may reach up to 6 feet in height (Beetle 1960, McArthur and others 1979). In contrast, Wyoming threetip sagebrush is a dwarf shrub typically growing from 18 to 24 inches tall (Tisdale 1994).

New growth begins in May and flowerheads develop in July with flowering occurring in August through October. Seed ripens in October (Beetle 1960). Table 48 presents the phenologic development of threetip sagebrush in eastern Idaho. Beetle (1960) also documented Wyoming threetip sagebrush blooming in August and September with seeds ripening in October.

Table 48—Threetip sagebrush phenologic development in eastern Idaho.

Developmental stage	Date
Leaf growth	April
Twig growth	Mid-June
Flowerheads emerge	Late June
Full bloom	Mid-September
Seed ripe	Mid-October
Seed disseminated	November

Source: Blaisdell 1953, Wright 1970.

Reproduction

Blaisdell (1958) noted that both subspecies of threetip sagebrush occasionally sprout from the root crown. However, the ability to sprout is limited by geographic location suggesting ecotypic variation (Barrington and others 1988). Under the right conditions it may also layer (Daubenmire 1970, Beetle 1960, McArthur and others 1979). Threetip sagebrush is a prolific seeder (McArthur and Stevens 1986), utilizing wind dispersed seed to reestablish following disturbance (Pendleton and others 1989, Schlatterer 1972).

Young (1983) described germination rates of threetip sagebrush as "moderate to rapid." In germination tests of tall threetip sagebrush response increased with increased stratification.

Optimum conditions for germination are at approximately 60^0 F (Marchand 1964). Seed can remain viable from 4 to 6 years in storage (Shaw and Monsen 1990).

Ecological Information

Threetip sagebrush is commonly found in shallow soils on steep slopes, exposed ridges, and knolls (Beetle and Johnson 1982, Carson and Peek 1987). Similarly, Wyoming threetip sagebrush is found in shallow rocky soils often surrounded by well-developed grasslands (Beetle 1960). In contrast, tall threetip sagebrush is found in moderate to deep, well-drained, loamy soils (Ellison 1960). Precipitation ranges from 12 to 16 inches annually in these communities where elevations range from 3,388 to over 7,000 feet (Blaisdell and others 1982, Cronquist and others 1994, Welsh and others 1987). Wyoming threetip sagebrush has been documented from 7,000 to 9,000 feet (Beetle 1960). Threetip sagebrush's limitation to the northern extent of the sagebrush region, exhibits its preference for cool, relatively moist sites (Tisdale 1994). Percent composition by weight of shrubs, grasses, forbs in the Great Basin some threetip sagebrush communities in table 49.

Table 49—Threetip sagebrush site characteristics.

Lifeform	Percent composition by weight	Site productivity (lb/ac)
Shrubs	22	450 to 1,100
Grasses	60	
Forbs	18	
Litter	High	

Source: Tisdale 1994.

These communities are often found in undisturbed areas. Threetip sagebrush is a component in climax Idaho fescue steppe communities of eastern Washington (Daubenmire 1972). Tall threetip sagebrush is important in climax communities in southern Idaho (Humphrey 1984) and Wyoming threetip sagebrush is an indicator in some sagebrush communities of

Wyoming (Tweit and Houston 1980). Associated shrubs include big sagebrush (*A. tridentata*), broom snakeweed (*Guterrezia sarothrae*), rabbitbrush (*Chrysothamnus* spp.), gray horsebrush (*Tetradymia canescens*), and curlleaf mountain-mahogany (*Cercocarpus ledifolius*). Important graminoids include bluebunch wheatgrass (*Pseudoroegneria spicata*), Idaho fescue (*Festuca idahoensis*), needle-and-thread (*Hesperostipa comata*), Sandberg bluegrass (*Poa secunda*), and Thurber's needlegrass (*Achnatherum thurberianum*) (Shiflet 1973).

Disturbance Response

Unlike many sagebrush communities, threetip sagebrush communities can support fire spread (Britton 1979). In addition, it may form nearly pure stands following fire (Pendleton and others 1954). Barrington and others (1988) report that without periodic fire it gradually increases in density and cover. In southern Idaho threetip sagebrush reaches preburn levels within 25 to 40 years (Barrington and others 1988), similarly Neuenschwander (No Date) reported recovery takes approximately 30 years. Threetip sagebrush is often mixed with mountain big sagebrush (*A. tridentata* ssp. *vaseyana*) and may reflect the influence of past fire which may have facilitated its establishment in big sagebrush habitats (Tisdale 1994). In general, populations in eastern Idaho seem to have the greatest resprout potential, while populations on the Snake River Plain of Idaho have low resprout potential (Bunting and others 1987). In the Great Basin, Bushey (1987) found only a small portion of the plants resprouted following burning.

Herbicide treatments may reduce threetip sagebrush by 50 to 70 percent (Murray 1988); however, (Schlatterer 1973) states that young plants will begin to seed back in within 5 to 10

years. While in other studies, threetip sagebrush resprouted following herbicide application (Blaisdell and others 1982, Schlatterer 1973).

Heavy grazing tends to favor threetip sagebrush (Tisdale 1994). In eastern Idaho, it increased in response to heavy spring use by sheep (Ellison 1960), whereas fall sheep use has resulted in plant decreases (Ellison 1960, Mueggler 1950, Wambolt 1996).

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Bud Sagebrush (Picrothamnus desertorum)

Bud sagebrush (*Picrothamnus desertorum* Nutt.) (UDSA 2004) is found in xeric communities of southwestern Montana, central Idaho, eastern Oregon, southern California, and into New Mexico, Arizona, and Colorado (Kartesz and Meacham 1999, USDA 2004, Wood and Brotherson 1986). This drought tolerant plant, occupying arid foothills and ridges, is not known to hybridize with any other species (Institute for Land Rehabilitation 1979, Wood and Brotherson 1986). It is a habitat and community type dominant throughout its range.

Physiology and Morphology

Bud sagebrush is a summer-deciduous (Chambers and Norton 1993) shrub growing from 4 to 10 inches tall and spreading from 8 to 12 inches wide (Institute for Land Rehabilitation 1979). Flower stalks become woody, dry spines following seed production. Bud sagebrush is reported as endomycorrhizal (Dittberner and Olson 1983).

Bud sagebrush may initiate growth in early March or in April, depending on site condition, and enters dormancy by late June (Chambers and Norton 1993). Flowers are produced in May (Hutchings 1954) and shed in late June (Institute for Land Rehabilitation 1979). In Nevada, Ackerman and others (1980) reported that plants went dormant when temperatures reached 104^0 F and broke dormancy only after fall rains. In Utah, Chamber and Norton (1993) found that when fall precipitation penetrated the soil profile from 9.8 to 11.8 inches bud sagebrush broke dormancy, producing only new leaves. Plants remain green throughout the winter and spring (Institute for Land Rehabilitation 1979).

The root system of this species is shallow and fibrous (Institute for Land Rehabilitation 1979) with a thick taproot growing to 6 inches deep (Wood 1966, Wood and Brotherson 1986).

Primary growth of the root system occurs within the top 6 to 21.7 inches of the soil profile. In gravelly conditions, Wood (1966) reported the roots may reach up to 6 feet in depth. Adventitious roots are reported in bottomlands when lower branches are completely covered by soil (Wood and Brotherson 1986).

Reproduction

Bud sagebrush reproduces by wind pollinated seed (Pendleton and others 1989) but may layer (Wood and Brotherson 1986). Seed production is limited because embryos often freeze due to early seasonal development (McArthur and others 1979). Bud sagebrush produces small seed, yielding 641,250/ounce (Belcher 1985). Germination rates are low due to failure of the flowerhead to separate and release the seed, or seeds germinating while still in the flowerhead (McArthur and others 1979, Wood 1966). Seedling establishment rates of 64 percent were documented as part of a wildlife improvement project in Wyoming (Shaw and Monsen 1990). In Utah, West (1994) compared the survival of plants in grazed and ungrazed plots. In ungrazed plots with normal precipitation survival rates from 1935 to 1968 ranged from 41 to 70 percent. A second cohort, in the same study, was likely influence by dry spring conditions in 1936 and had survival rates from 1 to 9 percent (West 1994). Wood (1966) hypothesized that soil must be wet for 30 days or bud sagebrush seedlings will not survive.

Ecological Information

Bud sagebrush sites are found in arid areas receiving 8 to 14 inches of precipitation (Institute for Land Rehabilitation 1979) with elevations ranging from approximately 2,300 to 8,000 feet (Kearney and others 1960, Hickman 1993, Harrington 1964, Schultz and McAdoo

2002, Welsh and others 1987). Soils at these sites are shallow, loamy, well-drained and slightly alkaline (Hutchings 1954, Institute for Land Rehabilitation 1979, Vest 1962). Bud sagebrush is a habitat type dominant and a community type dominant in several species combinations throughout its range (table 50). Species associated with bud sagebrush by ecosystem are presented in table 51.

Table 50—Bud sagebrush habitat and community types.

Description	Location
Spiny hopsage (*Grayia spinosa*)/bud sagebrush/Indian ricegrass (*Achnatherum hymenoides*)-CT	California[1]
Black greasewood(*S. vermiculatus*)/bud sagebrush/desert needlegrass (*A. speciosa*)-HT	Nevada[2]
Shadscale (*Atriplex confertifolia*)/bud sagebrush-CT	Nevada[2], Utah[3]
Shadscale/bud sagebrush/winterfat (*Krascheninnikovia lanata*)-CT	Nevada[4]
Shadscale/bud sagebrush/black greasewood-CT	Nevada[4]
Shadscale/bud sagebrush/bottlebrush squirreltail (*Elymus elymoides*)-CT	Nevada[4]
Black greasewood/shadscale/bud sagebrush	Nevada[4]

[1] Young and others 1977.
[2] Blackburn and others 1969a.
[3] Vest 1962.
[4] Blackburn and others 1969b.

Table 51—Bud sagebrush ecosystem associates.

Ecosystem	Associated species
Desert shrub[1]	Shadscale, fourwing saltbush (*A. canescens*), valley saltbush (*A. cuneata*), low rabbitbrush (*Chrysothamnus viscidiflorus var. stenophyllus*), winterfat, spiny hopsage, and horsebrush s pecies (*Tetradymia* spp.)
Salt-desert scrub[2]	Black greasewood, shadscale, Gardner's saltbush (*A. gardneri*), fourwing saltbush, spiny hopsage, and winterfat
Sagebrush[3]	Big sagebrush (*A. tridentata*), yellow rabbitbrush (*C. viscidiflorus*), rubber rabbitbrush (*Ericameria. nauseosus*), western wheatgrass (*Pascopyrum smithii*), Indian ricegrass, and bluegrass (*Poa* spp.)

[1] Banner 1992.
[2] Plummer 1974.
[3] Deblinger 1988, Plummer 1974.

Bud sagebrush fills all successional niches from colonizer to climax species. In California, Webb and others (1988) documented bud sagebrush as a pioneer species on disturbed sites. While in Utah, Vest (1962) recorded it as a mid-seral species on vegetated sand-dune communities. In Montana, Ross and Hunter (1976) found it to be a component of climax vegetation on dense clay and clayey soils.

Disturbance Response

Bud sagebrush is killed by fire (West 1994); however, fire in these communities is unlikely. Similar to shadscale, and other arid sagebrush species, bud sagebrush communities have sparse understory growth resulting in low fuel loads and sites that rarely burn (Humphrey 1974). Specific information on fire intervals and fuel loading is lacking.

Bud sagebrush is palatable to wildlife and domestic sheep (Van Dersal 1938). It decreases with browsing due to its yearlong palatability (Chambers and Norton 1993). Wood and Brotherson (1986) found bud sagebrush may be killed rapidly under heavy browsing. Hutchings (1954) recommends maximum removal of 50 percent of annual growth.

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SAGEBRUSH MODEL REVIEW

As a result of the continuing loss of sagebrush communities and because of the ecological importance and values of sagebrush and sagebrush communties the development of a decision support system (DSS) is essential to assist land manager with identification and prioritization of restoration and conservation alternatives. The purpose of this section is to identify and assess models that simulate shrub and grassland community attributes that may be applied to the sagebrush biome. Models can be characterized by subject matter, by modeling technique (from simple regression to advanced programming), or by the actual uses of models (Agarwal and others 2002) and there are a plethora of ecological models (see "The Register of Ecological Models" http://eco.wiz.uni-kassel.de/ecobas.html). Our approach in reviewing applicable models was to examine those that have been applied to rangeland ecosystems[4]. Crop models (eg., Ceres and EPIC) were not included in this report. However, EPIC (Erosion Productivity-Impact Calculator) is a submodel of PHYGROW which we did review. Crop models have stressed crop phenology as a function of accumulated heat degree days to predict crop yield while rangeland ecosystem models have often stressed carbon-nitrogen dynamics (mechanistic models) or vegetation change (stochastic models). Models specific or concentrating their application to the sagebrush biome, however, have not been developed. Of particular interest in our review was logic describing successional patterns and disturbance response, including fire models for rangeland ecosystems and rangeland models developed using hydrologic,

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[4] Models developed for analyses related to global climate changes such as BIOME-BGC (BioGeochemical Cycles) were not specifically reviewed, but information from these systems has been used in other model systems (see section on MAPSS where BIOMAP, a dynamic general vegetation model (DGVM), combines the MAPSS biogeography model and the BIOME-BGC biogeochemical cycling model).

biogeochemistry, meteorological, and various other submodels that "grow" vegetation associated with ecosystem processes as a means of providing information for development of a DSS (Decision support system) to aid natural resource managers with managing sagebrush communities.

This section is divided into five parts *Stochastic Simulation Systems, Mechanistic Simulation Systems, Fire and Fuel Models, GIS Models,* and *Model Summary and Overview.* Included in the discussion about stochastic simulation systems is successional pathway diagrams and additional logic for these systems. The section on *Mechanistic Simulation Systems* describes the function and behavior of models capturing various components of the sagebrush biome, including fire models and forage production models. The *GIS Models* section examines the attributes and results of GIS models used for vegetation assessment in the sagebrush biome. Finally an overview of the various simulation systems and a need for development of a rangeland vegetation simulator is presented in *Model Summary and Overview.* We stress that the type of model needed, a "Rangeland Vegetation Simulator" is one that will help "on the ground" land managers with the analysis, interpretation, and understanding of potential changes associated treatments (including no treatment) within different sagebrush ecological sites and function as a DSS tool. The RVS would include ecological models and visualization, as a tool to work with the public, at the ecological site level that could also be used in landscape simulation and analyses and included in GIS.

Stochastic Simulation Systems

RMLANDS, SIMPPLLE, and VDDT are some of the knowledge-based systems widely used to model vegetation change (McGarigal and others No Date, Beukema and others 2003, Lee

and others 2003). The following sections describe the attributes and logic used in to simulate sagebrush related landscapes using these models. A summary paragraph provides the reader with a comparision and overview of these stochastic simulation systems.

RMLANDS

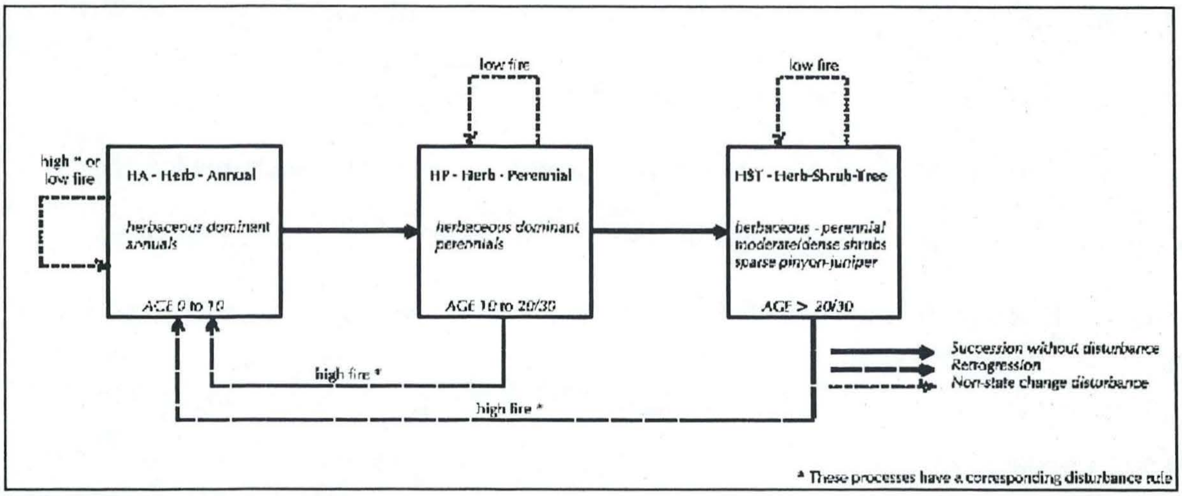
Rocky Mountain Landscape simulator (RMLANDS) is a spatially-explicit LDSS designed for Rocky Mountain landscapes. The model operates on grid-based system with 10-year time steps (McGarigal and others No Date). Successional information and disturbance response is represented by state and transition diagrams. A version of RMLANDS was built for the Uncompahgre Plateau in southwestern Colorado; containing four cover types which include sagebrush species. These types are the semi-desert savannah, sparse pinyon (*Pinus* spp.)-juniper (*Juniperus* spp.) woodland, pinyon-juniper woodland, and the pinyon-juniper-sagebrush woodland (Romme and others 2003).

Semi-desert savannah— this type is composed of scattered trees in a grassland matrix. Trees include two-needle pinyon (*Pinus edulis*) and Utah juniper (*J. osteosperma*). The dense shrub layer is dominated by shadscale saltbush (*Atriplex confertifolia*), Bigelow sagebrush (*A. biglovii*), winterfat (*Krascheninnikovia lanata*), and yellow rabbitbrush (*Chrysothamnus viscidiflorus*). Grasses are represented by James' galleta (*Pleuraphis jamesii*), blue grama (*Bouteloua gracilis*), and needle-and-thread (*Hesperostipa comata*). The state-and-transition diagram representing this cover type is presented in figure 11.

Sparse pinyon-juniper woodland— this type is characterized by a poorly-developed herbaceous understory. Due to the infrequent disturbance and harsh site conditions only one successional state is modeled. Dominant species include Utah juniper, two-needle pinyon, little

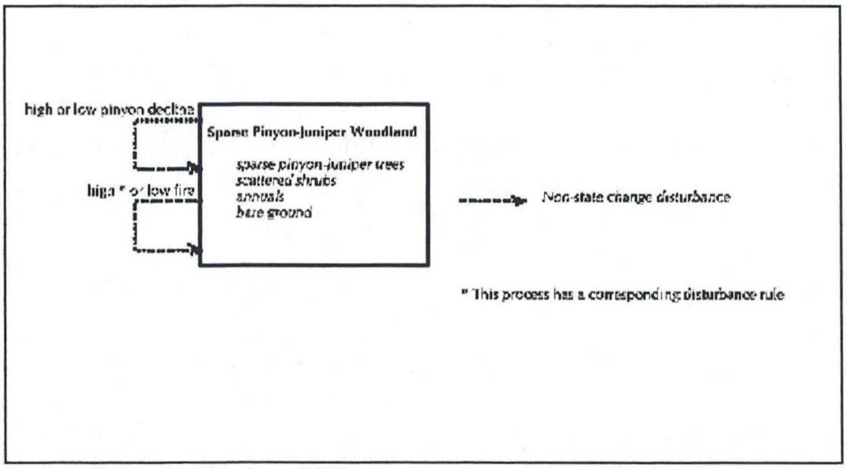
leaf mountain mahogany (*Cercocarpus inticatus*), single leaf ash (*Fraxinus amonala*), and Bigelow sagebrush (Romme and others 2003). The state-and-transition diagram representing this cover type is presented in Figure 12.

Figure 12—State-and-transition diagram for the semi-desert savannah of the Uncompahgre Plateau in RMLANDS.



Source: Romme and others 2003.

Figure 13—State-and-transition diagram for the sparse pinyon-juniper woodland of the Uncompahgre Plateau in RMLANDS.

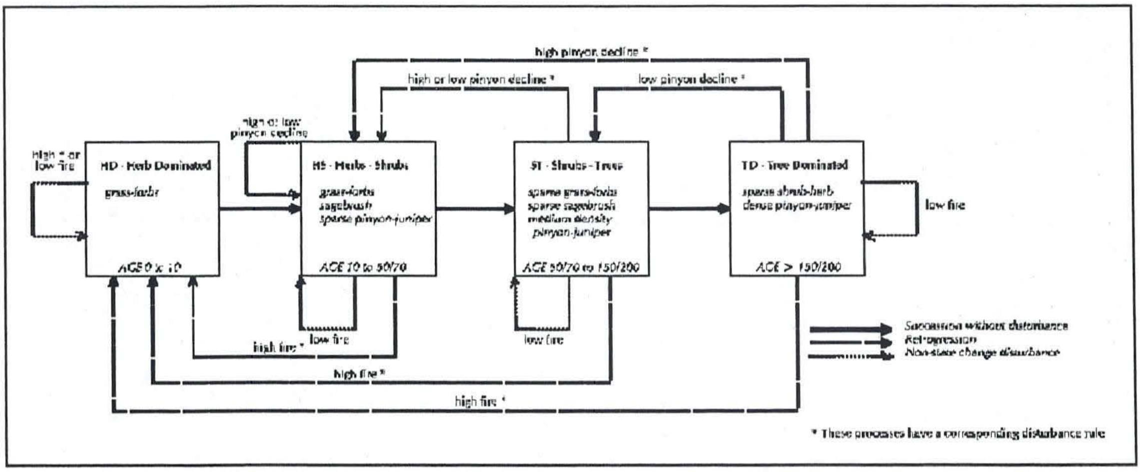


Source: Romme and others 2003.

Pinyon-juniper woodland— This type is characterized by sparse to dense two-needle pinyon and Utah juniper. A mix of low shrubs is present including antelope bitterbrush (*Purshia tridentata*), mormon tea (*Ephedra viridis*), and black sagebrush (*A. nova*). Herbaceous species

are represented by cool season species mutton grass (*Poa fendleriana*), Sandberg bluegrass (*P. secunda*), and western wheatgrass (*Pascopyrum smithii*). Warm season grasses include James' galleta, blue grama, and squirrletail (*Elymus elymoides*) (Romme and others 2003). The state-and-transition diagram representing this cover type is presented in figure 13.

Figure 14—State-and-transition diagram for the pinyon-juniper woodland of the Uncompahgre Plateau in RMLANDS.

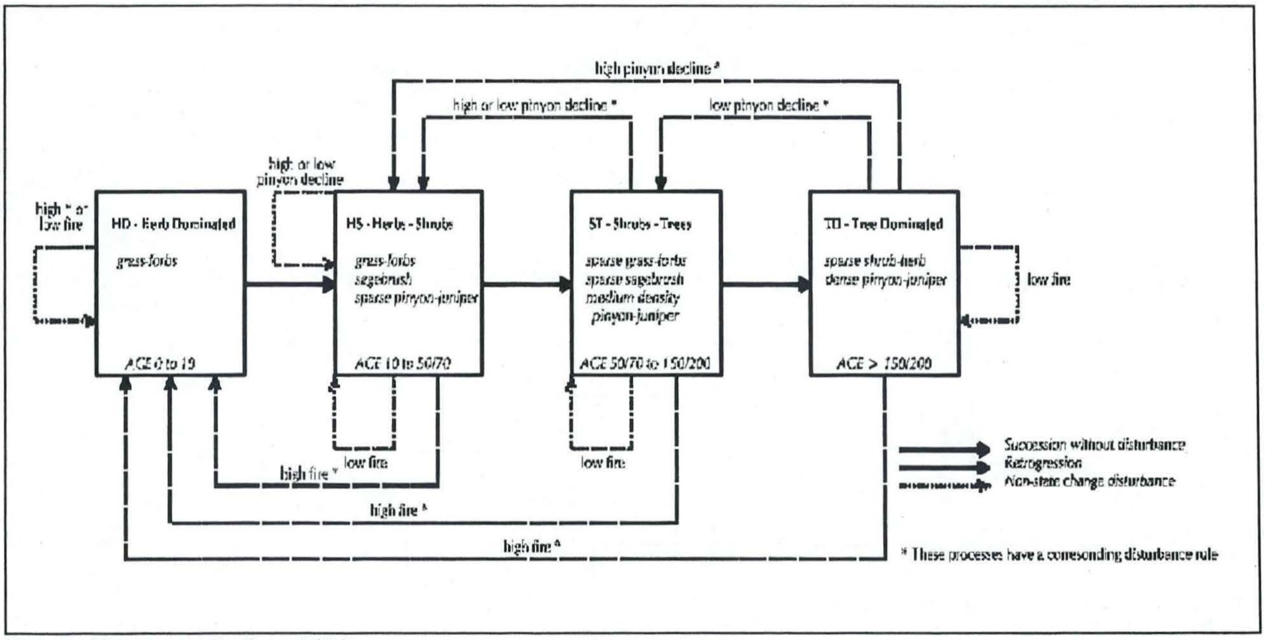


Source: Romme and others 2003.

Pinyon-juniper-sagebrush woodland—this type is composed of sparse to dense two-needle pinyon-Utah juniper cover with a variable understory of big sagebrush (*A. tridentata*). Herbaceous species include Sandberg bluegrass, western wheatgrass, James' galleta, blue grama, squirrletail among others (Romme and others 2003). The state-and-transition diagram representing this cover type is presented in Figure 14.

The RMLANDS model provides the user with successional categorization of the modeled ecosystem, including ages and community descriptions of states following disturbance factors, for the sites modeled. Stand variables such as height and coverage are are provided as general classes. Productivity and fuel loads are not modeled per se but could be added to community descriptions.

Figure 15—State-and-transition diagram for the pinyon-juniper-sagebrush woodland of the Uncompahgre Plateau in RMLANDS.



Source: Romme and others 2003.

SIMPPLLE

SIMPPLLE (Simulating Vegetation Patterns and Processes at Landscape Scales) is a management tool developed to provide an understanding of landscape dynamics (Chew 1995). It was not designed to predict the precise location and occurrence of landscape processes (i.e., succession, fire, insect and disease). Rather, SIMPPLLE provides a range of possible outcomes based on multiple stochastic simulations. This provides a prediction of general process trends for a specific landscape. These results can also provide a probability of occurrence for various processes and the associated plant communities on a yearly or 10-year time step (Chew and others 2004). In addition, SIMPPLLE is spatially-explicit. Therefore, the probability of a process occurring in a vegetation unit is influenced by the surrounding units and the past process history of those units. This design approach loses some detail present in other modeling systems,

but provides for interactions among processes and discrete vegetation units (Chew and others 2004).

The Colorado Front Range (CFR) version of SIMPPLLE models seven sagebrush community types (table 52). These types were grouped to form two distinct successional growth pathways (figures 15 and 16). The system knowledge is compartmentalized with pathways containing all possible vegetation states, for one species combination, represented by combinations of dominate species[5], size class[6] or structure, and canopy cover[7]. As a result, only limited information is stored in these pathways, including the ecosystem processes associated with the vegetation unit and the next state resulting from a particular process (Chew 2004).

Table 52—Sagebrush communities modeled in the CFR version of SIMPPLLE.

Species combination	SIMPPLLE code
Big sagebrush	ARTR2
Big sagebrush - alder leaf mountain mahogany	ARTR2-CEMO2
Big sagebrush - common juniper	ARTR2-JUCO6
Mountain big sagebrush	ARTRV
Mountain big sagebrush - antelope bitterbrush	ARTRV-PUTR2
Wyoming big sagebrush	ARTRW8
Wyoming big sagebrush - yellow rabbitbrush	ARTRW8-CHVI8

Source: Bedunah and Jones 2005.

Four particular habitat types documented by Tiedeman and others (1987) in Middle Park Colorado describe the community composition represented by SIMPPLLE (table 53).

Figure 17—SIMPPLLE successional pathway for big sagebrush and Wyoming big sagebrush communities of the CFR.

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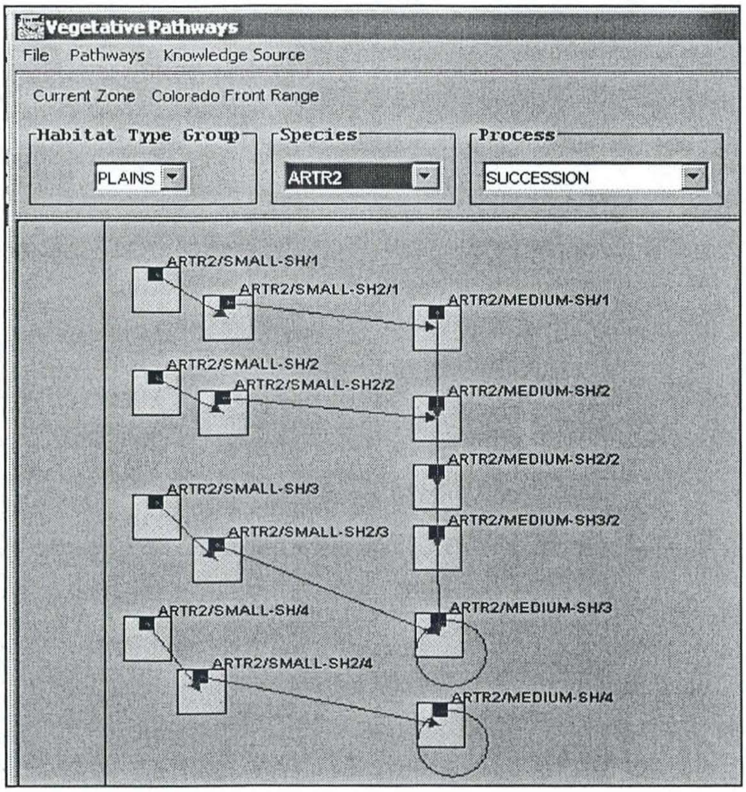
[5] Species are represented by four letter code as defined by the NRCS PLANTS database (USDA 2004).

[6] Shrub size classes for the CFR version of SIMPPLLE are: small (< 2.5 feet), medium (2.5 to 6.4 feet), and large (>6.5 feet).

[7] Species canopy cover classes are: 1 (0 to 10), 2 (11 to 40), 3 (41 to 70), and 4 (71 to 100).



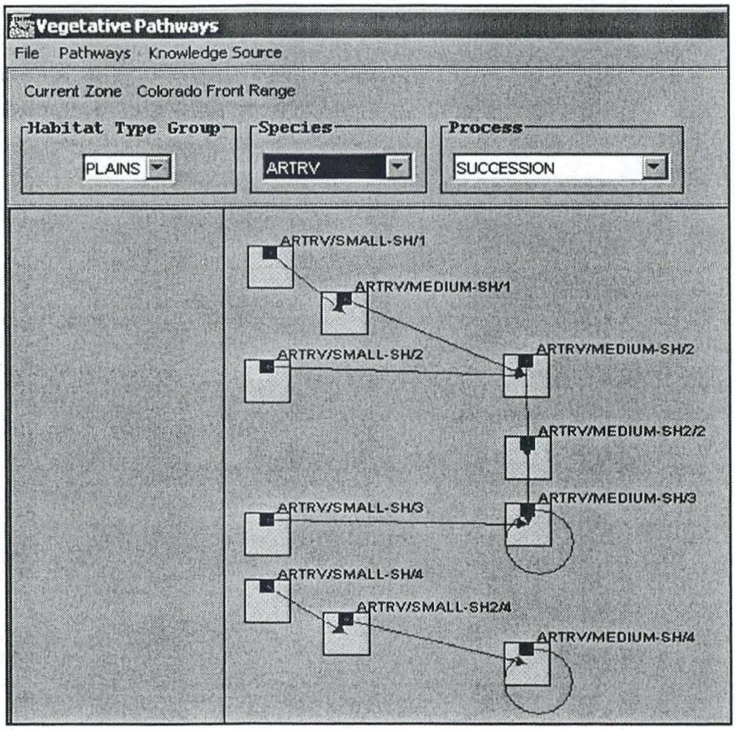


Table 53—Habitat type representation in the CFR SIMPPLLE version.

Habitat type	Associated shrubs	Herbaceous species

Habitat type	Associated shrubs	Herbaceous species
Wyoming big sagebrush-bluebunch wheatgrass (*Pseudoroegneria spicata*)	Yellow rabbitbrush	Bluebunch wheatgrass, mutton grass
Wyoming big sagebrush –needle-and thread	Yellow rabbitbrush	Needle-and-thread, western wheatgrass
Mountain big sagebrush-Thurber's fescue (*Festuca thurberi*)		Thurber's fescue, needle-and-thread, upland sedge (*Carex*) species
Mountain big sagebrush-Idaho fescue (*Festuca idahoensis*)	Mesic Shrubs	Idaho fescue, mutton grass

Source: Tiedeman and others 1987.

The development of SIMPPLLE non-forest communities is on-going. In simulated wildfire and fire suppression treatments in mountain big sagebrush and Wyoming big sagebrush communities, Jones (2005) found that regardless of treatment, acreage of the sagebrush types continued to increase over time. In addition, when testing a model component responsible for conversion of sagebrush to woodland or forest species due to fire suppression, the system converted a majority of the stands in the first decade and suppressed sagebrush regeneration after fire. These issues are currently being addressed by the developers. SIMPPLLE is a flexible system that can be updated to simulate a number of landscapes and is presently being updated to model communities of the Great Plains.

SIMPPLLE is a valuable tool for investigation of spatially explicit processes and their interactions across a landscape. In addition, the model provides the flexibility for the user to incorporate various vegetation treatments and fire probabilities in hypothetical situation to examine changes in vegetative canopy cover, size class, structure, and community type. The system does rely heavily on expert parameterization and adaptation of the model to new ecological types requires intensive developer assistance.

VDDT

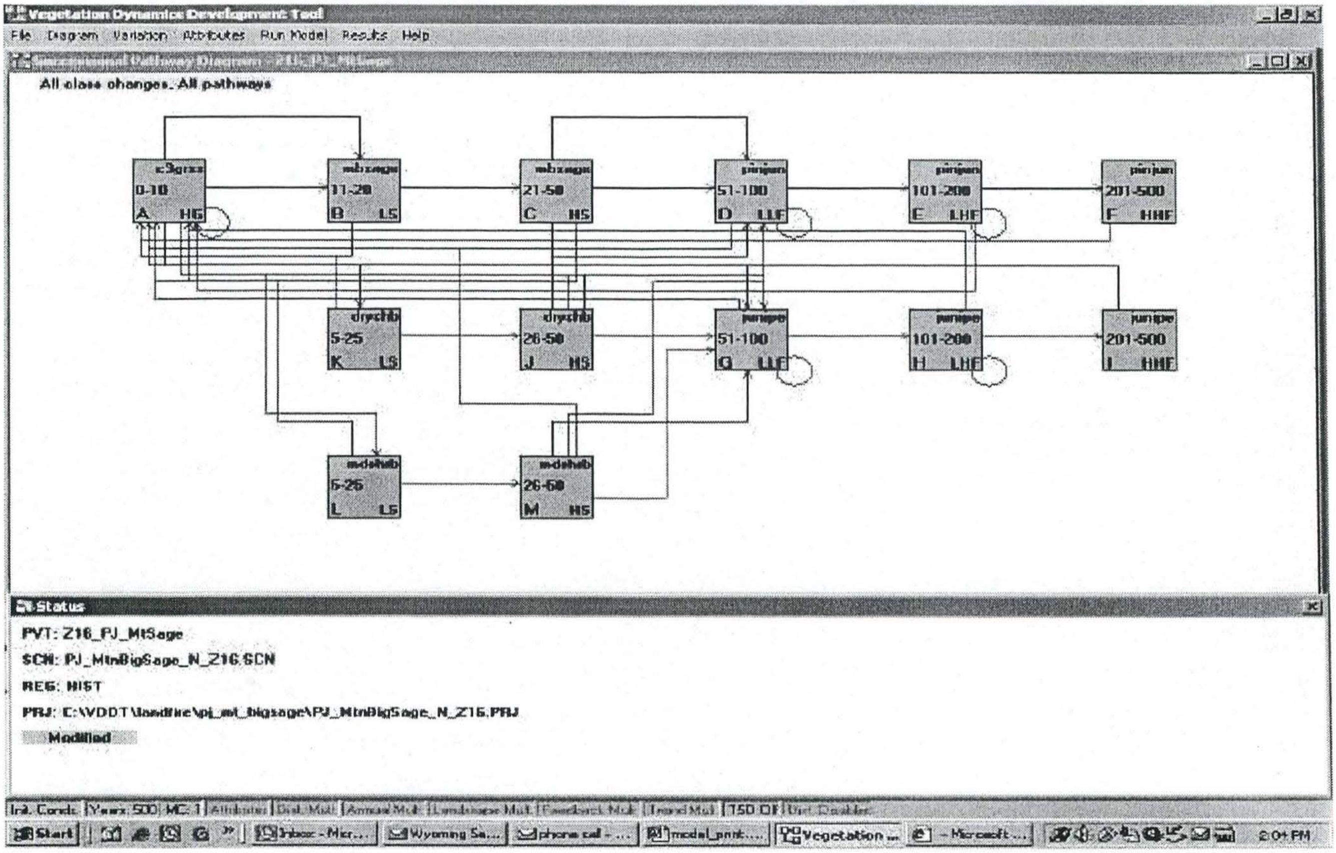
The Vegetation Dynamics Development Tool (VDDT) software provides a simple interface for the development and testing of aspatial vegetation dynamics models. These aspatial models can be used in examining the role of various disturbance agents and management actions by allowing users to create descriptions of vegetation dynamics in successional pathway diagrams (Beukema and others 2003). Landscapes are stratified into units with similar successional pathways, eg. Potential Vegetation Types (PVT). For each landscape stratification, vegetation states are defined as combinations of the predominant cover type and structural stage, called successional classes. Pathways between classes are defined in the pathway diagram as either changes driven by disturbance or changes due to stand dynamics in the absence of disturbance. Disturbance-relataed pathways specify, for each class, the type of disturbance, its probability, and its impact on the vegetation. Stand dynamic changes are defined by the time a stand remains in a structural stage (or cover type) and by the successinal class it will move to after this time (Beukema and others 2003). A detailed description of the model and software are presented in the VDDT User's Guide (Beukema and others 2003).

Numerous sagebrush PVTs have been modeled using VDDT as part of the ongoing LANDFIRE project. These models are presently in review. The developed models include successional classes, historical disturbances (fire, grazing, insects, etc. if known), and fire frequencies (historical or without exotic invaders that may influence fire regimes). Figure 17 illustrates a draft VDDT model of Pinyon-Juniper/Mountain big sagebrush type in northern Utah. Each box represents a succession class within the PVT (Pinyon-juniper/Mountain big sagebrush Northern Utah) and is described by a unique combination of cover type (upper right corner) and structural stage (lower right corner). The arrows show the pathways between classes.

Succession pathways start and end on the vertical sides of boxes while disturbance pathways start and end on the top or bottom of boxes. The age range of the succession class is shown in the middle part of the box. The entire diagram is referred to as a successional pathway diagram. For the model simulations, the landscape is partioned into a number of pixels, each initially assigned by the modeler and age. The model simulates the probability of each pixel being affected by one of the disturbance types, and if a disturbance does occur, moves the pixel to the class defined in the pathway diagram (Beukema and others 2003). Each pixel is indendent of the state of the neighboring pixels and their disturbance history. Thus, the model does not simulated cantagion in space or time (Beukema and others 2003).

As VDDT sagebrush PVT models are published they will provide additional information on disturbance regimes and successional classes for areas throughout the western U.S. Succession class information will provide information on cover and height of successional classes, but these may be somewhat general (e.g., low cover and high cover or low height and moderate height). Productivity and fuel loads are not modeled per se but could be added to community descriptions. Beukema and others (2003) state that the most important contribution of the VDDT modeling framework is that it provides a common platform for specialists to collectively define the roles of various processes and agents of disturbance on landscape-level dynamics. The model allows for rapid gaming and testing of the senitiviy of the system to alternative assumptions and thus provides a tool for learning and communiciation (Beukema and others 2003). Recently, the aspatial VDDT models have been used a component of the spatial landscape dynamics model, LANDSUM, in the Landfire Project to understand and characterize landscape vegetation dynamics over time (Beukema and others 2003).

Figure 18—Potential vegetation type diagam illustration of VDDT for the mountain big sagebrush PVT in Utah.



Stochastic Simulation System Overview

The models, VDDT/TELSA (Tool for Exploratory Landscape Scenario Analysis), SIMPPLLE, and RMLANDS can be used to understand changes in vegetation characteristics over time as well as portray patterns of spatial change. While these models have the same general objectives, the different conceptual approaches to meeting those objectives have set distinctly different model emphasis. VDDT promotes flexibility and an open structure (Lee and others 2003) allowing for the efficient development of vegetation classes and process relationships (Beukema and others 2003). SIMPPLLE has a relatively sophisticated state space and ecological resolution (Lee and others 2003) and emphasizes behavioral validity and trends (Chew and others 2004), while RMLANDS has very high spatial resolution and elaborate spatial

processes (Lee and others 2003) to capture the range and patterns of landscape structural variability (McGarigal and others No Date).

Despite these conceptual differences, these systems provide similar output data. In reviewing these systems, Lee and others (2003) established five criteria to compare system capabilities, 1) the ability to predict known vegetation successional pathways; 2) the ability to provide information for decision making among alternative vegetative pathways; 3) the ability to determine necessary vegetation treatments for pathway alteration; 4) are the systems based on current scientific literature; 5) could these systems serve as a linear optimization model? All three of the LDSS were able to meet the objectives of the first four questions to varying degrees. None of the systems are capable of serving as a linear optimization system (Lee and others 2003).

Further review of these models highlighted the strengths and weaknesses of each system. VDDT's strengths are the inherent flexibility in landscape states coupled with its direct portability to other landscapes, along with the models utility as an educational/training tool (Lee and others 2003). In addition, Barrett (2001) found VDDT to be helpful in developing an understanding of vegetation pathways with an interface that allows for easy alterations. In comparison, SIMPPLLE has a high level of biological detail and some available documentation (Lee and others 2003), and is useful in visually depicting the range of possible future vegetation (Barrett, 2001). While RMLANDS' strengths are its high spatial resolution and direct linkages to FRAGSTATS and wildlife habitat models that provide additional information based on the most detailed science and methodologies (Lee and others 2003).

Drawbacks to each modeling system are few and of minor consequence depending on questions being asked. VDDT is less scientifically and analytically rigorous in representing

landscape relationships. Furthermore, the model needs to be used in conjunction with TESLA to capture spatial relationships inherent in both SIMPPLLE and RMLANDS. Whereas SIMPPLLE and RMLANDS, require the developer to write the initial landscape pathways for new areas, significantly increasing the time and cost associated with planning efforts (Lee and others 2003).

Barrett (2001) recommended improved documentation for VDDT and SIMPPLLE[8]. VDDT is the only model with both a user's manual and a tutorial data set. SIMPPLLE has a draft user's manual with training exercises. However, vegetation pathway documentation, the result of workshops with resource specialists, is not available. Romme and others (2003) provided extensive documentation of the landscape cover types and their associated logic for the Uncompahgre Plateau landscape in southwestern Colorado for RMLANDS. Documentation of this nature supplies decision makers with a fundamental understanding of the model, limiting the "black box" notion associated with LDSS. Moreover, thorough documentation provides an avenue for peer review, timely system updates as new research findings become available, and aid in communication of forest dynamics with non-professionals (Barrett 2001). Given the pros and cons of the various models, neither Lee and others (2003) or Barrett (2001) preferred one model over the others in relation to forest planning.

Mechanistic Simulation Systems

Several mechanistic systems capture herbaceous and shrubland productivity. These models often include submodels simulating hydrology, soils, climate, plant attributes, herbivory, nutrient cycling, and erosion among other environmental parameters. The following section

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[8] RMLANDS was not reviewed by Barrett (2001).

describes the attributes and logic used in several mechanistic models to simulate sagebrush related landscapes.

CENTURY Soil Organic Matter Model

CENTURY is an agroecosystem model first published by Parton and others (1987). The CENTURY model simulates carbon, nutrient, and water dynamics for different types of ecosystems and has been used extensively in rangelands and other rangeland models. CENTURY includes a soil organic matter/decomposition sub-model, a water budget sub-model, two plant production sub-models (grassland and forest), and functions for scheduling events(Ojima and others, no date). The model computes flows of carbon, nitrogen, and (optionally), phosphorus, and sulfur through model compartments. Ojima and others (no date) state that carbon uptake in CENTURY is controlled primarily by nitrogen availability and the soil organic matter sub-model includes three soil organic matter pools with different potential decomposition rates. The water budget model calculates monthly evaporation, transpiration, water content of the soil layers, snow water content, and saturated flow of water between soil layers and both plant production sub-models (a grassland/crop sub-model and a forest production sub-model) assume that the monthly maximum plant production is controlled by moisture and temperature, and that maximum plant production rates depend on the availability of nutrients (Ojima and others, No date). The grassland/crop production model simulates plant production for different herbaceous crops and plant communities (e.g., warm or cool season grasslands). To simulate savanna or shrubland ecosystems, CENTURY combines the grassland and forest sub-models with simulation of nutrient competition and shading effects.

CENTURY conceives disturbances as central components of an "equilibrium" ecosystem, and applies a natural disturbance regime during equilibrium simulation. Disturbances such as fire, harvest, grazing and cultivation are simulated via the management and events scheduling functions (Ojima and others, nd). Variables included in CENTURY are monthly total precipitation (cm), soil texture (sand, silt, clay and % of rock-free volume), plant nitrogen, phosphorus, and sulfur content, lignin content of plant material, atmospheric and soil nitrogen inputs, and initial soil carbon, nitrogen (phosphorus and sulfur optional) are provided to the model as input variables. The CENTURY model uses a monthly time step which has been reported to result in model discrepancies. For example, Gilmanov and others (1997) found that CENTURY reproduced the seasonal, mid-term, and in some cases, long-term dynamics in aboveground biomass in a wide range of grassland ecosystems across the former USSR, but short-term responses to intermittent rainfall were missed by the monthly timestep of the model. They also report that model discrepancies were attributed to changes in species composition. Parton et al. (1993) found that CENTURY simulated soil C and N levels and peak live biomass and production within 25% of the observed values; atthough, short-term changes in biomass were not predicted well by the model.

In summary, CENTURY is primarily designed to capture nutrient flow through various plant systems. The system models the effect of various disturbance processes on available nutrient pools and subsequent plant response (NREL 2005). However, the model does not provide successional information for plant communities, or the ability to track invasive species. Furthermore, it appears the vegetative growth parameters for PHYGROW are more detailed; however, CENTURY is often coupled with other models that will be discussed (i.e., SAVANNA, SPUR, and MAPSS) and PHYGROW has adapted logic from CENTURY

(Ranching Systems Group 2003) providing for models to simulate plant biomass, nutrient cycling, disturbance, and in some cases successional changes.

COVER

COVER is an extension of the Prognosis model. COVER describes the amount of cover and foliage in the tree canopy by height class, the height and cover of shrubs, forbs, and grasses in the understory, and a summary of overstory and understory cover and biomass for a stand. The shrub subcomponent of COVER is calibrated from over 10,000 1/300-acre forest plots in northern Idaho, northeastern Washington, and northwestern Montana, central and southern Idaho, and northwestern Wyoming (Moeur 1985). Thus, the focus of this extension was not the Intermountain Sagebrush Steppe, or the Great Basin—Colorado Plateau Semi-arid desert but the logic and methods used are of use if the appropriate plot data is available.

The shrub submodel first calculates probability that shrub cover exists; providing coverage is greater than zero, the probability of occurrence for each species is then calculated. Following this, shrub height is then predicted and the species are sorted from tallest to lowest. Individual species cover is calculated, as well as the amount of overtopping cover and weighted by probability of occurrence. The probability of shrub occurrence in the stand and total shrub cover are based on the work of Laursen (1984), while the probability of individual species occurrence is based on the logistic multiple regression work of Scharosch (1984) (based on 10,000 plots located in 500 stands) (Moeur 1985). Twig production and dormant season shrub biomass are predicted for three habitat types and is based on the work of Irwin and Peek (1979). The variables used to calculate shrubs species probability of occurrence, height, and percent cover are presented in table 54.

Table 54—Parameters for predicting probability of occurrence, height, and percent cover for shrubs in COVER.

Categorical Parameter	Continuous Parameters
Overstory climax species (includes habitat type)	Overstory basal area (ft^2/acre)
Understory climax union (includes habitat type)	Stand elevation (100's of feet)
National forest grouping	Elevation square (10,000's of feet)
Physiography	Total percent shrub cover
Type of site disturbance	Slope (percent/100)
Type of site disturbance x overstory basal area	Slope x sin(aspect)
Type of site disturbance x time since disturbance	Slope x cos (aspect)
	Time since site disturbance (years)
	Overstory basal area x time since disturbance

Source: Moeur 1985.

Challenges in applying this methodology to sagebrush communities include the lack of plot data to calibrate a model of this type. There is a lack of literature such as the work of Laursen (1984) and Scharosch (1984) on predicting shrub composition, cover, and structure following disturbance in many sagebrush communities. Frandsen (1983) developed leaf and woody biomass estimates for fuel classes based on the work of Uresk and others (1977) and Rittenhouse and Sneva (1977). Thus, it is possible that additional plot data, for example plot data collected by the U.S. Forest Service or Bureau of Land Management, could be located to better calibrate a sagebrush specific model following this methodology.

Mapped Atmosphere-Plant-Soil System (MAPSS)

MAPSS was developed to simulate potential biosphere impacts and biosphere-atmosphere feedbacks from climate change. The model simulates landscape to global scale vegetation distribution. It uses two different ecosystem nutrient cycling models and a process-based fire model to capture spatially explicit dynamics of vegetation under stable and changing climates (Neilson and others, No date). The model does not simulate biomes directly; rather, it simulates the distribution of vegetative lifeforms and converts those lifeforms into vegetation classifications at the biome level. MAPSS currently represents 45 unique vegetation types with

considerable importance placed on semi-arid, savanna, shrubland, grassland, and desert communities. MAPSS was unable to discriminate between salt desert and sagebrush vegetation in the Great Basin (Neilson and others, No date). The addition of new dynamic vegetation models, MC1 and BIOMAP, are used to explore management options at all spatial scales (USDA 2005b). Originally MAPSS was a steady-state model representing potential natural vegetation for any upland site in the world under present, past or future climate. The system assumes ecosystems tend to maximize the leaf area that can be supported by the available moisture and energy on site (USDA 2005b).

Biomes are not expressly simulated in the system; the distribution of trees, shrubs, and grasses is modeled by dominant leaf form (broadleaf, needleleaf), leaf phenology, thermal tolerances, and vegetation density and combined into biome level classifications (USDA 2005b). Leaf area is calculated for woody and herbaceous vegetation in competition for light and water. Site water balance accounts for runoff and surface soil layers are apportioned to the two life forms in relation to their respective leaf area index (LAI) and stomatal conductance (Neilson and others, No date). MAPSS contains eight fundamental algorithms for:

1. formation and melt of snow,
2. interception and evaporation of rainfall,
3. infiltration and percolation of rainfall and snowmelt through three soil layers,
4. runoff,
5. transpiration based on LAI and stomatal conductance,
6. biophysical 'rules' for leaf form and phenology,
7. iterative calculation of LAI, and
8. assembly rules for vegetation classification (USDA 2005b).

Currently two Dynamic Vegetation Models (DVM) are being constructed to aid in the exploration of management alternatives. DVM are a combination of biogeochemistry models, which simulate carbon, nitrogen, and water, and biogeography models that predict vegetation

distribution under varying climates. The MC1 (MAPSS-CENTURY, Version 1) model is transient and was originally constructed under the Vegetation/Ecosystem Modeling and Analysis Project (VEMAP) as an integration of MAPSS biogeography model and the CENTURY biogeochemical model. MC1 currently simulates 22 vegetation types (Neilson and others, No date). In addition to the biogeography and biogeochemical models a fire process model is incorporated to simulate the occurrence and impacts of fire events that are infrequent yet extreme. The fire module captures the occurrence, behavior, and effects of severe fire. The module uses algometric equations based on lifeform composition as simulated by the biogeography module to translate aboveground biomass into fuel classes. Fire effects are estimated as a function of simulated fire intensity and spread on existing vegetation composition. These effects modify carbon and nutrient pools in the biogeochemistry module (Neilson and others, No date).

BIOMAP is a dynamic general vegetation model (DGVM) meshing the MAPSS biogeography model and the BIOME-BGC biogeochemical cycling model, in addition to a fire process model. This model captures the interactions between vegetation distribution, nutrient cycling, productivity, and disturbance. Vegetation change is driven by disturbance, competition, and succession. The 'savanna' structure is the general ecosystem structure in MAPSS; simulating competition between woody plants and grasses over multiple soil layers with differential rooting depths. Light competition follows Beer's law and soil biogeochemistry was adapted from CENTURY. Preliminary work in ponderosa pine savannas of eastern Oregon suggest the model captures complex vegetation dynamics with site dominance switching over hundreds of years between trees and grasses depending on long-wave soil nitrogen dynamics and fire within a semi-arid climate (USDA 2005b).

The MAPSS system has been successfully validated against 100 years of fire data and has been used to investigate the expansion of woody species with climate change and fire suppression. However, the system estimated 10 times the acreage burned as compared to actual acres. Model developer hypothesized the overestimate could reflect the mitigation of fire impacts due to fire suppression efforts. Sagebrush steppe, low elevation ponderosa pine, and pinyon-juniper communities were simulated (USDA 2004).

MAPSS appears to capture highly detailed biogeographic and biogeochemical information in a spatially explicit format; something other modeling systems have been unable to achieve with the same success. In addition, this system captures succession, competition, and disturbance as well as community productivity. Other systems tend to categorize productivity or community dynamics but seldom both. Moreover, MAPSS has been used to investigate pinyon-juniper and sagebrush steppe species response to climate change and fire as well as capture cheatgrass invasion under increasing CO_2 concentrations. Some identified problems of the MAPSS modeling system include the overestimation of acreage burned under wild fire conditions and the systems inability to separate salt desert vegetation from sagebrush communities.

Phytomass Growth Simulator (PHYGROW)

PHYGROW is a point based, daily time step model that simulates above ground plant growth, forage consumption, and hydrologic processes. System algorithms are a compilation of logic from the Chemical Runoff and Erosion from Agricultural Management Systems (CREAMS), Groundwater loading effects of Agricultural Management Systems (GLEAMS), Erosion-Productivity Impact Calculator (EPIC), Erosion Prediction Model (WEPP), Simulation

Production and Utilization of Rangelands (SPUR), CENTURY, and Ekalaka Rangeland and Hydrologic and Yield Model (ERHYM-II), models in addition to grass tiller and dietary selection research conducted at Texas A&M University. PHYGROW is comprised of four major subcomponents including soils, plant community/species attributes, grazer stocking rules/plant preferences, and weather (Ranching Systems Group 2003).

PHYGROW has been used in a variety of ways to capture plant production/herbivore interactions. In East Africa, the system is being used for a Livestock Early Warning System (LEWS) across seven countries. A version of LEWS is being piloted in three regions of Texas as well. National Oceanic and Atmospheric Administration (NOAA) 0.25 degree weather system now drives a full automated version of PHYGROW. Furthermore, this weather data is being linked to a fuel moisture/fire behavior model to create a fire risk assessment system. PHYGROW has been validated throughout the dry and wet tropics, temperate grasslands, shrublands and desert regions of the United States (Ranching Systems Group 2003).

Detailed plant species parameters are required for site simulations. Table 55 lists the parameters required for each species and/or site. In addition, water stress, temperature stress, and effective green leaf area index are characterized.

Table 55—Species parameters required for site simulations with PHYGROW.

Parameter	Parameter definition[1]
Leaf area index	cm^2 total leaf area/cm^2 unit land area
Dry matter to radiation conversion ratio	grams dry matter/mega joule radiation
Suppression temperature (C^0)	Average daily temperature leaf extension ceases
Base temperature (C^0)	Average daily temperature leaf extension commences
Leaf turnover percentage	percent of standing crop which is replaced (summer and winter dormancy)
Heat units accumulation at seed	sum of positive increments of differences between base temperature and average daily temperature until seed ripening
Heat unit accumulation at death	sum of positive increments of differences between base temperature and average daily temperature until stem elongation ceases or flowering is initiated
Maximum rooting depth (cm)	maximum rooting depth possible for the species (independent of soil depth)
Maximum canopy height (cm)	maximum genetic expression of canopy height for the species

Maximum above ground biomass (kg/ha)	maximum amount of biomass that can occupy 0.25, 0.5, 1.0 m^2 site depending on spacing of individuals on site
Leaf to above ground biomass ratio	mass (kg) of leaves/total above ground biomass (kg) for all lifeforms (grasses equal 1)
Stem area index	area of stems/ plant canopy (dry weight)
Leaf water storage capacity (g H_2O/g DM)	amount of water that adheres to the surface of leaves and evaporates into the atmosphere
Stem water storage capacity (g H_2O/g DM)	amount of water that adheres to the surface of stems and evaporates into the atmosphere
Fraction of water transferred from leaf to stem	canopy intercepted fraction of water that travels from leaf to stem
Stem turnover rate	percent old growth, and primary wood that turns over each day
Cold unit accumulation to freeze leaf damage	accumulation of negative differences between current days average temperature minus the base temperature
Leaf green to dead rate (senescence rate)	daily green dead transfer rate of current years growth – percent green standing crop
Leaf green to dead rate during dormancy	daily green to litter transfer rate at dormancy of current years growth – percent green standing crop
Canopy base diameter (cm)	maximum genetic expression of canopy diameter at the base of the plant
Canopy crown diameter (cm)	maximum genetic expression of canopy diameter expected from the plant
Height at canopy start (cm)	height at which the canopy diameter begins
Height at beginning of canopy curvature (cm)	height to the widest part of the canopy diameter of the plant (maximum genetic expression)
Maximum leaf litter decomposition rate	percent of leaf litter decomposing daily
Maximum stem litter decomposition rate	percent of stem litter decomposing daily
Leaf litter water storage capacity (g H_2O/g dry matter)	water adhesion per unit leaf dry matter
Stem litter water storage capacity (g H_2O/g dry matter)	water adhesion per unit stem dry matter
Contribution to range site hydrologic condition	values between 0.1 and 1.0 which reflect species contribution to the hydrology of the site
Minimum required day length to grow for each plant (hours)	values of zero to 24 (value of zero means plant always grows)
Initial standing biomass (kg/ha)	Estimate of initial standing biomass for each species
Relative yield	percent of potential niche occupancy that a species is currently expressing in a community
Site nutrient factor (optional)	value between 0.0 and 1.0

Source: Ranching Systems Group 2003
[1] Assumes water is not limiting.

System algorithms adapted from other models primarily describe soil, water, and transpiration interactions. PHYGROW utilizes a version of "matrix flow" or soil inter-layer water movement. Runoff calculations follow that of ERHYM-II (which is presented in CREAMS) with logic from EPIC and SPUR. Evaporation and evapo-transpiration are modified by both ERYHM-II and WEPP logic. Potential transpiration incorporates logic from EPIC,

WEPP, and SPUR. Soil percolation is not included in ERHYM-II model so logic for this function is adapted from SPUR. Temperature stress logic is adapted from the CENTURY model. Incorporation of relevant components from the previously listed modeling systems has resulted in a system that adequately captures soil/water parameters, a wide range of vegetative species growth, and species specific grazing influences (Ranching Systems Group 2003).

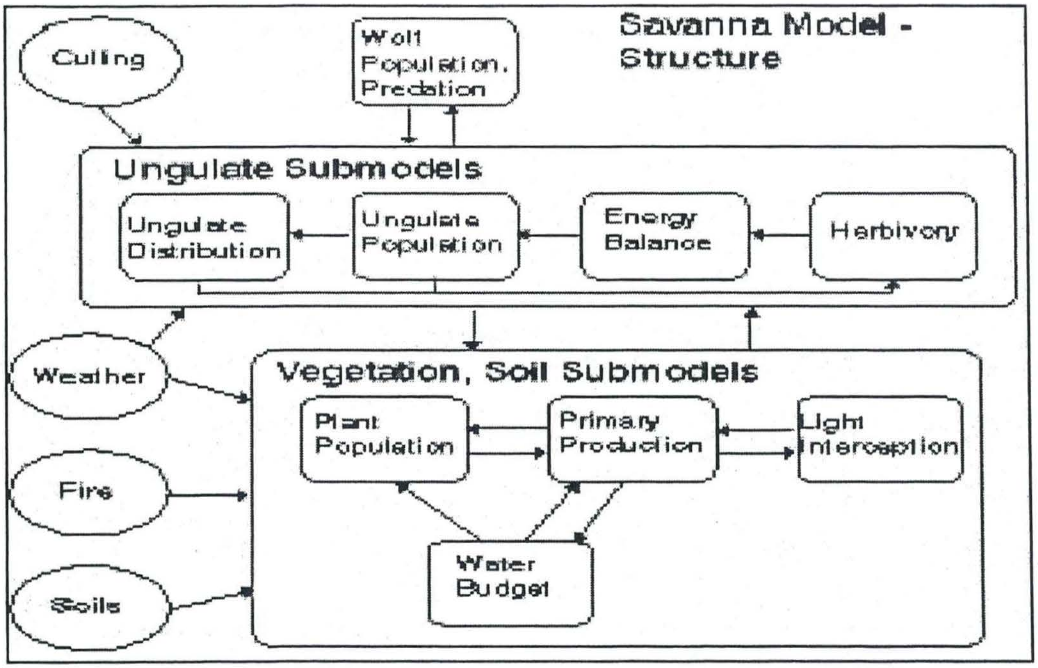
PHYGROW is a fundamental component in the Burning Risk Advisory Support System (BRASS) project in 25 counties in Arkansas, Louisiana, Oklahoma, and Texas. Vegetation types represent 64 stands including upland and lowland pine plantations, pine plantations on pasture or old cropland, hardwood woodlands, and pasture lands. Combined with NOAA 0.25-degree gridded daily weather data and 1-hour fuel models PHYGROW produces fine fuel load estimates at each site. PHYGROW was coupled with the Fuel Moisture Stick (FMS) model to capture fuel moisture by fuel class, and the BEHAVE fuel model to provide ignition characteristics, primarily flame length, and rate of spread. This is a fully automated system updating continuously as new weather data is available. Tests are underway to determine if linking the system to MODIS NDVI greenness data will produce reliable 16-day fine fuel load maps (USDA 2005c).

PHYGROW is lacking the ability to capture community successional changes and some ecological processes important in community succession. The system seems to be well designed to estimate fuel loads and burning characteristics; however, ecological influences such as invasive species changes, insects and disease, and succession following disturbance such as fire are not captured in the current system. In sagebrush ecosystems it is important to capture changes resulting from species conversion or changes in disturbance processes such as fire. Addition of a succession/disturbance component and the logic developed from another model (eg., URM) may improve the system.

SAVANNA

SAVANNA (ver. 5) is a spatially explicit, process-oriented model of grassland, shrubland, savanna, and forested ecosystems that was originally developed to study nomadic pastoral ecosystems in Kenya. The model operates on a weekly time step and simulates processes at landscape through regional scales on an annual or decadal scale. Critical components of the model include site water balance (monthly weather station data), plant biomass production, plant population dynamics, litter decomposition and nitrogen cycling, ungulate herbivory, ungulate spatial distribution, ungulate energy balance, and ungulate population dynamics submodels (figure 18). SAVANNA simulations have been applied to a variety of locations including Kenya, Elk Island National Park in Alberta, Pryor Mountain Wild Horse Range, Rocky Mountain National Park in Colorado, northern Australia, South Africa, Tanzania, and Inner Mongolia (Coughenour No Date). SAVANNA has been calibrated and used to simulate sagebrush communities in Yellowstone and the Pryor Mountain Wild Horse Range (Coughenour pers. comm. 2005).

Figure 19—SAVANNA ecosystem simulation model component structure.



Source: Coughenour 2000.

The SAVANNA model links net primary production (NPP) submodel with light, water, temperature, nitrogen, and herbivory. Herbaceous biomass is allocated to leaves, stems, and roots while woody biomass is allocated to leaves, fine branches, coarse branches, fine root, and course root. Shrub ecophysiology was parameterized largely based on information for sagebrush. This system component is highly detailed capturing photosynthesis and stomatal conductance, photosynthate allocation, respiration, transpiration, tissue senesces rate, and root turnover among other attributes (Coughenour No Date).

Plant population submodels simulate species establishment, size, and mortality. Establishment rates are influenced by water and temperature and woody cover to reflect the effects of shading. A vegetative growth rate versus shoot to root ratio function simulates the effects of climate stress or grazing. In addition, a micro-scale disturbance rate can be set to kill plants at a given rate to reflect the herbivore or human impacts. Fire, grazing, and harvest are the

major disturbance processes influencing plant communities in SAVANNA (House and others 2003).

Application of SAVANNA for management of wild horse populations in the Pryor Mountains showed the model preformed well in capturing herbaceous plant growth and impacts due to herbivory across a wide range of sites and weather years. Grasses, forbs, shrubs, mountain mahogany, juniper, and coniferous forests were simulated for this project. After comparison with ground data, the model adequately simulated the proportions of grasses and forbs, the live to dead rate of transfer, and the rate of transfer of dead tissues to soil. Moreover, the model correctly represented biomass production across the study area (Coughenour 2000). SAVANNA has already been used to simulate sagebrush communities, and with further calibration could be used for sagebrush biome communities of the Great Basin (Coughenour e-mail February 25, 2005).

SAVANNA has been linked to the soil organic matter model CENTURY (House and others 2003). The CENTURY-Savanna model is more generalized than SAVANNA, simulating competition for water, nutrients, and shade effects. Trees have preferential access to N depending on basal area and site fertility. In contrast, SAVANNA allocates N equally to various lifeforms in proportional demand in different patches and rooting zones (House and others 2003).

SAVANNA is a highly mechanistic, spatially explicit model with the ability to simulate community production and landscape disturbance processes such as fire and grazing. In addition, the system has been previously calibrated for and applied to sagebrush communities. Although the system does not include community response to invasive species, one may be able to work around this using the complex interactions between grass/shrub/tree resource competition. It is unclear how the model treats post-fire community change or if cheatgrass

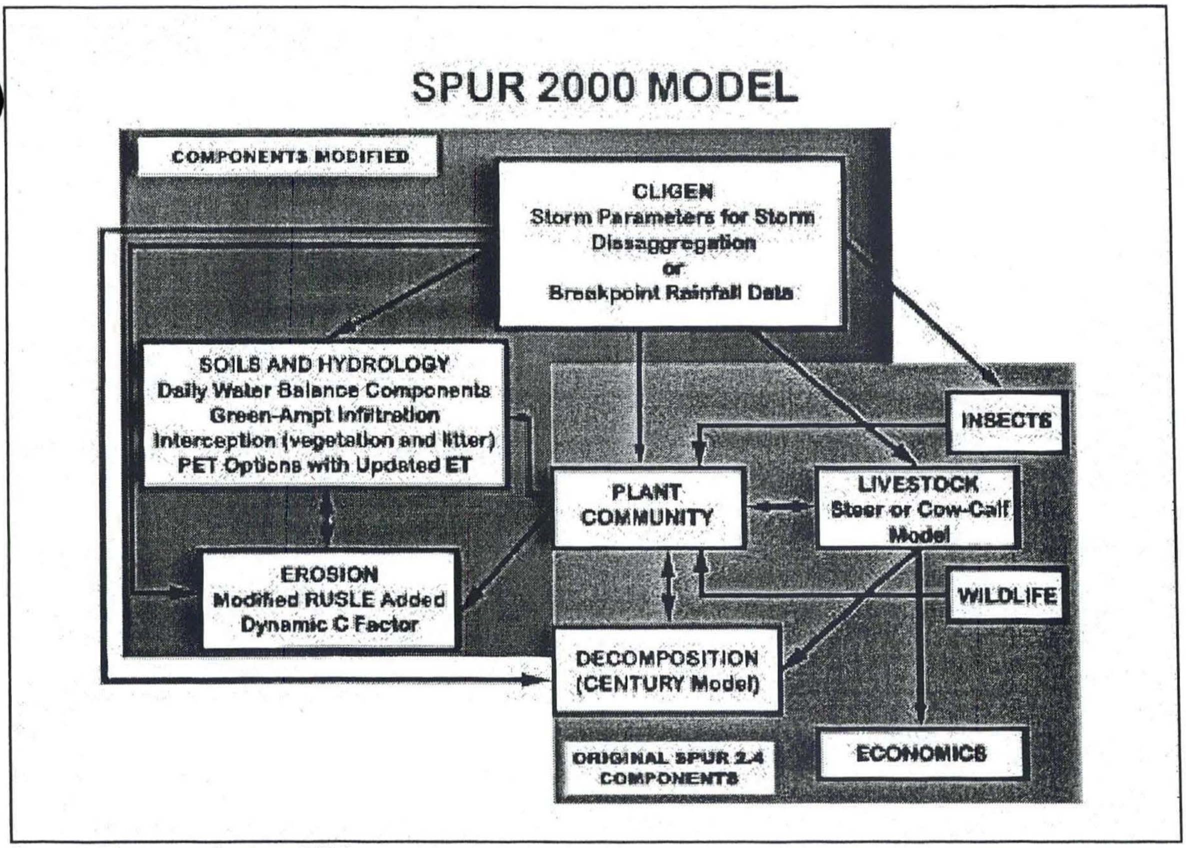
invasion could be simulated, but the system does deal with population changes and species recruitment (House and others 2003).

Simulation of Production and Utilization of Rangelands (SPUR)

SPUR was originally designed to capture forage growth and utilization by grazing animals, as well as predict hydrologic and erosion changes due to management alternatives in semiarid environments (Pierson and others 2001). Currently, the system has the ability to model plant growth, carbon and nitrogen cycling, soil moisture flux, surface hydrology, erosion, foraging by wildlife, and economics of beef production. Updated versions of the model have improved landscape process logic, making components interactive during long simulations and allowing for dynamic changes in system states (figure 19).

SPUR is a point-based system operating on a daily time step (Skirvin and Moran 2003). Point-based systems are often limited to small areas of homogenous conditions and do not extrapolate well to larger, diverse landscapes (Teague and Foy 2002). As a result, a raster-based spatially explicit (SESPUR) version with a GIS component has been developed. SESPUR can now model a mosaic of soils, vegetation, and topography (Skirvin and Moran 2003).

Figure 20—SPUR 2000 submodels and component relationships.



Source: Pierson and others 2001.

Under low cover conditions it is difficult to capture soil evaporation and plant evapotranspiration. SPUR incorporates three equations to capture potential evapotranspiration, the Priestly-Taylor, Penman-FAO, and the Penman-Montieth equations (Pierson and others 2001). Plant growth is responsive to temperature, soil water and nitrogen availability, seasonality, and herbage removal and trampling. In addition, SPUR has been successfully combined with the hydrologic model Water Erosion Prediction Project (WEPP) and a climate generator (CLIGEN) to form the vastly improved WEPP/SPUR modeling system. The combination of these process models has improved the climate input data on a daily basis and the infiltration and runoff models of WEPP (Pierson and others 2001).

The WEPP/SPUR system has been used by the United States Department of Agriculture (USDA) Agricultural Research Service (ARS) to simulate wet meadows in the Intermountain

region of Idaho and assist in Ecological Site Descriptions for high elevation mountain big sagebrush sites in northwestern Nevada. In Idaho, the simulations were found to successfully capture the water budget, deep percolation, soil moisture, sediment loss, and changes in vegetation composition for willow (*Salix* species)/sedge-rush (*Carex-Juncus*) communities (Spaeth and others 2004a). Developers have linked the data stored in the Ecological Site Information System to the WEPP/SPUR model as a tool to better develop ecological site descriptions (Spaeth and others 2004b).

Initial validation of SESPUR occurred on the Walnut Gulch experimental watershed in southern Arizona. The validation identified the need for adjustments to soil parameters, peak vegetation growth, and adjustments to correct for underestimates in biomass. In addition, the model requires significant parameterization and calibration. Current research is rectifying these issues, and the development of a user-friendly GIS interface is being developed (Skirvin and Moran 2003). Following these adjustments, SPUR will be one of the only point-based forage productivity models that have the ability to capture landscape scale process changes in vegetation mosaics.

The WEPP/SPUR system appears to be a sound tool to assess vegetation change and productivity in sagebrush communities. The advantages of this system are its ability to incorporate landscape processes and vegetative community change with forage production. No other system reviewed has integrated these two functions. If the spatially explicit SESPUR could be integrated with the WEPP/SPUR system this would allow for enhanced fire modeling and process spread due to the addition of slope, aspect and other parameters.

Understory Response Model (URM)

URM was developed as part of the Applied Wildland Fire Research in Support of Project Level Hazardous Fuels Planning by the Environmental Consequences team. The URM is a system that predicts qualitative changes in shrub, forb, and grass biomass at 1, 5, and 10-year intervals caused by fuel treatment activities. The system is based on species-specific traits such as life form, reproductive method, etc. and site specific effects such as soil heating (USDA 2005a). Species-specific attributes are required to direct model behavior. Attributes include life span, life form, root location, bud location, vegetative regeneration, weed, sprout, shade tolerance, seed dispersal, seed bank, heat stimulated seeds (Steve Sutherland 2005).

The URM system is limited to simulating fire response for one species in its current configuration. Successional changes due to disturbance are not captured either. However, the logic in this system may be an enhancement in understory species if coupled with a community succession/productivity model.

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Fire Models

Numerous fire spread and behavior models exist. Many of these models base there fire spread and behavior algorithms on the work of Rothermel (1972) and Albini (1976). The fuel models they constructed are also the basis of the National Fire Danger Rating System (NFDRS). Scott and Burgan (2004) are currently constructing a series of new standard fire behavior fuel models. These new models, while based on the original 13 fuel models (Rothermel 1972, Albini 1976), include a dynamic component tied to herbaceous moisture content. Incorporation of herbaceous moisture content should improve the ability of modeling systems to capture fire behavior and spread rates. However, all of these fuel models are still based on the assumptions of homogeneous and continuous fuels, which is seldom the case in arid shrub communities. The violation of these assumptions led Brown (1982) to develop a specific set of regression equations to capture sagebrush fire behavior. Frandsen (1983) proceeded to develop fuel load values for various height classes of basin big sagebrush and Wyoming big sagebrush. Britton and others (1981) present a curve relating herbaceous and big sagebrush canopy cover to fire spread. The following section details this information in an effort to streamline the process of adapting existing fire modeling systems to semi-arid sagebrush types.

Anderson (1982)

Anderson's (1982) report *Aids to Determining Fuel Models for Estimating Fire Behavior* is based on the 13 fuel models of Rothermel (1972) and Albini (1976). These fuel models are the basis of the NFDRS and used in several fire behavior models including BehavePlus, FARSITE, and FlamMap (Anderson 1982, Andrews and others 2003). Brown (1982) reported that arid land shrub types violate the inherent assumption of continuous and homogeneous fuels

found in the Rothermel models. Brown (1982) presented alternative fuel and fire behavior models for big sagebrush types (see discussion below). More recently, Scott and Burgan (2004) constructed a series of new standard fire behavior fuel models. These new models include a dynamic component for any fuel type with an herbaceous component. In these dynamic models the herbaceous load shifts between live and dead depending on the specified live herbaceous moisture content. While these improvements should help characterize fire behavior in some types, these models are still based on the assumptions used by Rothermel (1972) of homogeneous and continuous fuels. Therefore, these models are still subject to the criticism of Brown (1982).

Fuel load and depth are important factors in predicting fire ignition, rate of spread, and intensity. Grasses and brush have, vertically oriented fuel loads; depth increases rapidly as fuel loads increase (Anderson 1982). Anderson (1982) places sagebrush/perennial grass communities in fire behavior fuel model two (table 56). Fire spread through this fuel model is driven by cured or nearly cured herbaceous material. Open shrublands, pine stands, and some pinyon-juniper stands fit this model. In the shrub fuel model group pinyon-juniper sagebrush is in group six (table 59). Fire carries through the shrub layer with the aid of moderate winds, greater than 8 mi/hr (Anderson 1982). Fire burns understory vegetation and openings under low winds. Anderson (1982) states that while pinyon-juniper types are included in this fuel model, rate of spread may be over-predicted except in high winds (greater than 20 mi/hr at the 20 foot level). This information, while generalized to classify the variation found across communities, is valuable for estimating community fuel loads and fire behavior in broad terms. But again, these models are based on the assumption that fuels are continuous and homogeneous which is seldom the case in arid shrub communities.

Table 56—Fuel model values for potential sagebrush communities.

Fuel model	Fuel loading (tons/acre)				Fuel bed depth (feet)	Moisture of extinction dead fuels (percent)
	1 hour	10 hour	100 hour	Live		
Two: timber (grass and understory)	2.00	1.00	0.50	0.50	1.0	12
Six: dormant brush, hardwood slash	1.50	2.50	2.00	.00	2.5	25

Source: Anderson 1982.

Brown (1982)

Brown (1982) modeled fuel and fire behavior in big sagebrush communities[9] which showed the extent that rate of spread and fireline intensity vary by height, percent cover, foliage moisture, and fraction dead stemwood. Brown (1982) found age correlated poorly to crown area, height, and bulk density. Rate of spread for cured vegetation were two to three times greater than for uncured. The proportion of dead stemwood had little effect on predicted fire behavior. Litter coverage averaged 52 percent while loading of litter, including bareground, averaged 78 g/m^2. Grass loadings were highly variable ranging from 22 to 224 g/m^2 with a median value of 88 g/m^2; forb median loading was 20 g/m^2 over the sample area. Furthermore, preliminary modeling showed that for large sagebrush plants, litter had little influence on fireline intensity and rate of spread. In contrast small sagebrush plants litter significantly influenced fire behavior. As a result, in small sagebrush communities Brown (1982) used an average litter load of 690 lb/ac. Litter distribution had little influence on predicted fire behavior and was modeled as a uniform distribution (Brown 1982).

[9] Prediction of fire spread and intensity was made using the mathematical models of Rothermel (1972). As a result, the regression equations developed for sagebrush communit ies are those required as input for the fire spread and intensity model.

Validation of the predictive models of Brown (1982) showed good agreement between observed and predicted rate of spread but poor agreement for flame length and intensity. Regression equations developed to describe sagebrush fuel and fire behavior are presented in table 57 (Brown 1982). Equations for estimating fuel loading and foliage surface area-to-volume ratio are presented in table 58.

Table 57—Regression equations for predicting sagebrush fuel and fire behavior[1].

Regression equation	Sub-species	Number plants	R^2	Standard error	A	b
	Vas.	89	0.71	0.5732	-10.1554	1.9092
In A = a + b(InH)	Wyo.	89	0.67	0.5712	-10.2372	1.9254
	All	178	0.69	0.5690	-10.1944	1.9168
	Vas.	89	0.22	0.5919	-3.0553	0.6693
In BD1 = a + b(InH)	Wyo.	89	0.38	0.5949	-1.2526	-1.0903
	All	178	0.29	0.3629	-2.2274	-0.8604
	Vas.	89	0.60	0.0191	0.3410	-0.05007
F = a + b(InH)	Wyo.	89	0.50	0.0137	0.2700	-0.03242
	All	178	0.55	0.0170	0.3088	-0.04210
P1 = a + b(1/H)	All	178	0.48	0.0261	0.4072	2.2318
P2= a + b(H)	All	178	0.46	--	0.9796	-0.002454
BD2 = b(BD1)	All	178	0.99	0.00091	NS	1.8286
	Vas.	89	0.23	0.7148	-2.7913	0.5407
InD = a + bIn(age)	Wyo.	89	0.28	0.7245	-3.3661	0.6166
	All	178	0.24	0.7380	-3.0742	0.5772

Source: Brown 1982.
[1] A = crown area, square meters;
H = plant height, centimeters;
BD1 = bulk density of foliage and 0.0 to 0.6 cm stemwood, grams per cubic centimeter;
BD2 = bulk density of foliage plus 0.0 to 2.5 cm stemwood, grams per cubic centimeter;
F = fraction of foliage
P1 = fraction of foliage plus 0.0 to 0.6 cm stemwood;
P2 = fraction of foliage plus 0.0 to 2.5 cm stemwood; and
D = fraction of 0.0 to 0.6 cm stemwood that is dead.

Table 58—Equations for predicting sagebrush fuel loading and surface area-to-volume ratio[1].

Attribute	Equation
Fuel loading for Wyoming big sagebrush	$m = 10^{-2.2522} A^{0.5553} H^{1.1780}$ (foliage) $m = 10^{-3.1639} A^{0.7409} H^{1.7351}$ (woody biomass)
Surface area-to-volume	o = 2/t (foliage) o = 4/d (woody biomass)

Source: Brown 1982.

[1] Values were not presented for mountain big sagebrush.
m = weight, grams
A = crown area, square centimeters
H = sagebrush height, centimeters
o = surface-to-volume ratio, cm^{-1}
t = leaf thickness, cm
d = stem diameter, cm

Frandsen (1983)

Frandsen (1983) developed characteristic basal diameters for basin big sagebrush and Wyoming big sagebrush for the whole plant that correspond to crown dimensions. Basal diameters were used to derive woody biomass by size class and finally leaf and woody biomass as classified by 3 fuel size classes. Basin big sagebrush data was based on the work of Uresk and others (1977) while data for Wyoming big sagebrush came from Rittenhouse and Sneva (1977). The regression coefficients used to relate biomass to plant height and canopy area are presented in table 59. The relationship derived to relate canopy area to plant height is presented in table 60. Various equations important in developing sagebrush fuel loads are presented in table 61. Fuel parameters for different height and canopy area ranges for individual shrubs of basin big sagebrush and Wyoming big sagebrush are presented in table 62.

Table 59—Regression equation and coefficients relating biomass to plant height and canopy area.

Subspecies		Regression equation	Regression coefficients			R^2	Observations
			b_0	B_1	b_2		
Basin big sagebrush	Leafy	$M=10^{b_0}A^{b_1}H^{b_2}$	-0.8348	0.2042	1.2324	0.67	20
	Woody		-0.0664	0.8100	0.9535	0.81	20
Wyoming big sagebrush[1]	Leafy		-0.6750	0.5553	1.1780	0.97	26
	Woody		0.2699	0.7409	1.7351	0.96	26

Source: Frandsen 1983.
[1] Frandsen (1983) eliminated questionable observations from Rittenhouse and Sneva (1977).
M = leaf or woody biomass in kilograms
A = canopy area in square meters
H = plant height in meters

Table 60—Regression equation and coefficients relating canopy area to plant height.

Subspecies	Regression equation	Regression coefficients		R^2	Observations
		c_0	c_1		
Basin big sagebrush	$A=10^{c_0}H^{c_1}$	0.8003	1.5254	0.54	867
Wyoming big sagebrush[1]		-0.8471	2.2953	0.79	66

Source: Frandsen 1983.

[1] 40 additional observations are from Carlton Britton for Wyoming big sagebrush.

Table 61—Formulas used to develop fuel load classes.

Attribute	Equation
Basal stem diameter	$M_l = 4.968\, D^{1.888}$ $M_w = 18.52\, D^{2.314}$
Biomass partitioning[1]	$F_1 = D/(3.763D-1.460)$ $F_{10} = 1-F_1$ $F_{10} = D/(4.095D-5.154)$ (A) $F_{100} = 1 - F_1 - F_{10}$
Shrub volume	$V_1 = 4p(w_1/2)^2(w_2/2)/3$ $V_2 = p(w_1 + H)^2 w_2/24$
Shrub area	$A = p\, w_1\, w_2/4$

Source: Frandsen 1983.

[1] If the shrub basal stem diameter was less than or equal to 0.5 cm it was assigned completely to the 1h size class, if the diameter was equal to or greater than 0.5 cm but less than 2.0 cm it will extend into the 10h size class.

[A] If the diameter was equal to or greater than 2.0 cm but less than 7.0 cm, the fraction F_1 remains unchanged.

M_l = leaf biomass in grams

M_w = woody biomass in grams

D = basal diameter in grams

F_1 = woody biomass fraction in the 1h size class

F_{10} = woody biomass fraction in the 10h size class

F_{100} = woody biomass fraction in the 100h size class

V_1 = assumes shrub is an oblate spheroid

V_2 = assumes shrub height is less than the major axis

w_1 = major shrub axis in meters

w_2 = minor shrub axis in meters

A = shrub area in meters squared

Table 62—Fuel parameters for different height and canopy area ranges for individual shrubs of basin big sagebrush and adjustments for Wyoming big sagebrush.

Height (m)	Canopy area (m^2)	Fuel load[1] (kg/m^2)				Volume (m^3)	Bulk density (kg/m^3)
		Leaves	1h	10h	100h		
0.4-0.6	0-0.05	0.83	0.47	0.87	0	0.010	5.5
	0.05-.10	.39	.34	.60	.10	.026	4.2
	.10-.15	.28	.29	.46	.18	.042	3.6
	.15-.20	.23	.27	.39	.20	.085	3.0
	.20-.30	.18	.25	.34	.22	.13	2.5
	.30-.45	.14	.22	.28	.22	.13	2.5
0.6-0.8	0.5-.10	.59	.52	.76	.38	.039	4.4
	.10-.20	.38	.43	.57	.42	.072	3.8
	.20-.30	.28	.37	.47	.42	.12	3.3
	.30-.50	.21	.34	.40	.41	.19	2.9

	.50-.75	.15	.30	.34	.39	.30	2.5
0.8-1.0	.10-.20	.51	.45	.56	.51	0.97	3.3
	.20-.40	.34	.39	.46	.49	.18	2.8
	.40-.60	.24	.35	.40	.46	.30	2.4
	.60-.90	.20	.32	.36	.44	.46	2.1
	.90-1.20	.14	.30	.33	.42	.66	1.9
1.0-1.2	.20-.30	.47	.48	.56	.62	.20	2.9
	.30-.50	.35	.44	.50	.59	.30	2.6
	.50-.70	.28	.41	.44	.57	.45	2.3
	.70-1.00	.19	.37	.41	.54	.63	2.1
	1.00-1.30	.15	.35	.38	.52	.86	1.9
	1.30-1.60	.12	.34	.36	.50	1.11	1.7
Table modifications for Wyoming big sagebrush:							
Applicable range				**Column multipliers**			
0.4-0.6	0-0.45	1	1	1	1	1	7
.6-.8	0.05-.75	1	1	1	1	1	1
.8-1.0	.10-1.20	1	1.5	1.5	1.5	1	1.5
1.0-1.2	.20-.70	1	1.8	1.8	1.8	1	1.7

Source: Frandsen 1983.

[1] Load class: 1h, 10h, 100h
Size range: 0 to 0.63 cm, 0.64 to 2.54 cm, 2.55 to 7.62 cm

In a more recent study, Reiner (2004) quantified fuel loads in sagebrush steppe/pinyon juniper types for three of the most abundant shrub species. She developed estimations of fuel subparts (1,10, 100 and 1,000 hour live and dead, with fuels greater than 3 inches constituting the 1,0000 hour fuels) for Wyoming big sagebrush, mountain big sagebrush and rabbitbrush. The categories found to best predict Wyoming big sagebrush fuel size class distributions from average percentages were 0, 1 to 15, 16 to 50 and 51 to 100 percent dead (table 63). Categories for mountain big sagebrush were 0 to 15, 16 to 50 and 51 to 100 (table 64). Categories for rabbitbrush were 0, 1 to 50 and 51 to 100, reflecting that rabbitbrush had a higher ratio of live to dead material (table 65). The distributions of the big sagebrush species were similar, as both had a majority of the plants in the 16 to 50 percent dead category. The rabbitbrush differed in that over one-half of the plants were in the lowest percent dead category, having no discernable dead material (figure 14). It is unknown if these dead classes would accurately reflect these shrub species for different areas.

Table 63. Average percentages of live and dead fuel subparts for *Artemisia tridentata wyomingensis* by field estimated percent dead category.

	Live				Dead		
Dead (%)	1 hour	10 hour	100 hour	1000 hour	1 hour	10 hour	100 hour
0	0.270	0.122	0.430	0	0	0	0
1 to 15	0.155	0.147	0.595	0.021	0.54	0.461	0
16 - 50	0.158	0.280	0.467	0	0.559	0.328	0.113
51 to 100	0.156	0.234	0.536	0	0.405	0.387	0.209

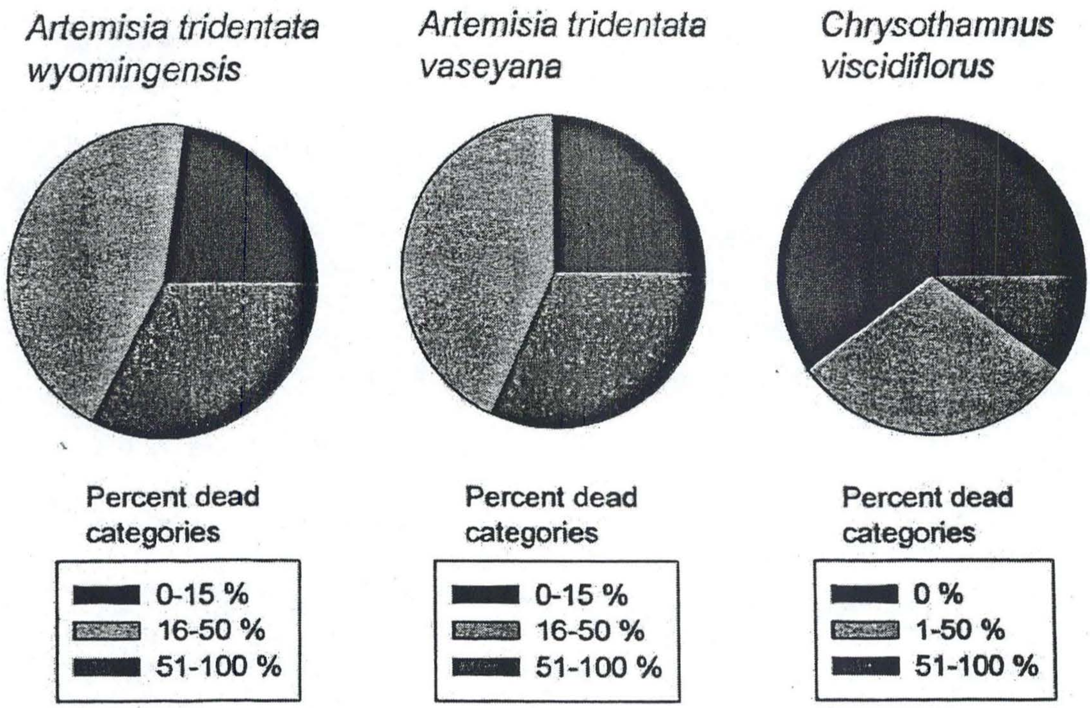
Table 64. Average percentages of live and dead fuel subparts for *Artemisia tridentata vaseyana* by field estimated percent dead category.

	Live				Dead		
Percent dead	1 hour	10 hour	100 hour	1000 hour	1 hour	10 hour	100 hour
0 to15	0.258	0.264	0.259	0	0.562	0.115	0.322
16 to 50	0.167	0.230	0.480	0	0.549	0.292	0.159
51 to 100	0.098	0.188	0.635	0	0.404	0.325	0.272

Table 65. Average percentages of live and dead fuel subparts for *Chrysothamnus viscidiflorns* by field estimated percent dead category.

	Live			Dead	
Dead (%)	1 hour	10 hour	100 hour	1 hour	10 hour
0	0.629	0.006	0	0	0
1 to 50	0.583	0.129	0	0.985	0.015
51 to 100	0.478	0.236	0	0.848	0.152

Figure 21. Percent of plants within dead classes (from Reiner, 2004, p. 41).



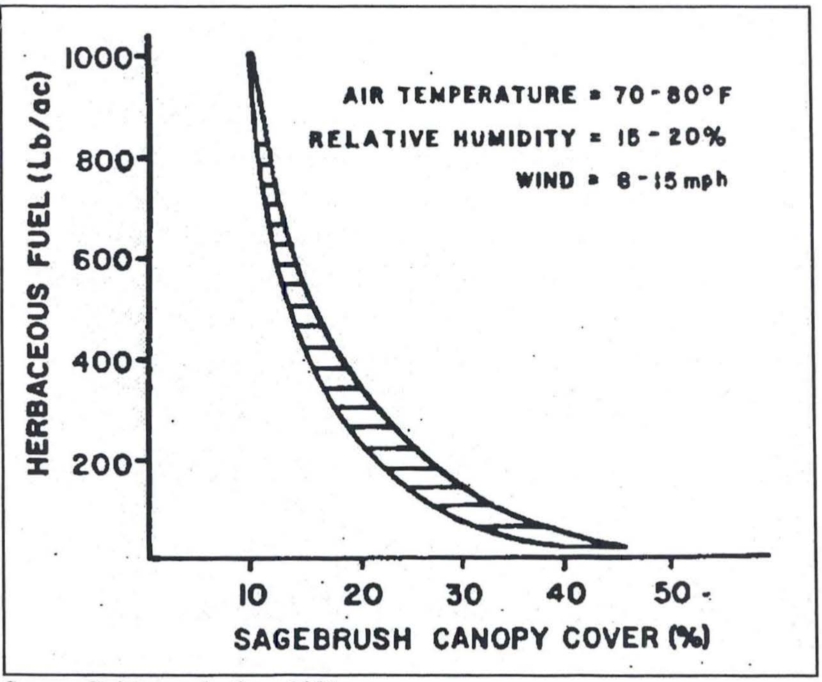
The fire models of Rothermel (1972) have been criticized for their inability to capture fire behavior in fuel types with heterogeneous and discontinuous fuels. The work of Rothermel (1972) is still the standard by which current fire behavior models such as BehavePlus base their fire behavior logic. It appears that with the work of Brown (1982) and Frandsen (1983) fire behavior models could be updated and calibrated to enhance sagebrush fire behavior. Regardless, over 20 years have passed without significant research improvements in sagebrush fire behavior. As issues such as sage grouse habitat loss, pinyon-juniper invasion, and cheatgrass understory conversion take place, there is justification for renewed research of sagebrush fire spread and behavior.

Britton and others (1981)

Britton and others (1981) present a curve representing the relationship between sagebrush canopy cover and herbaceous fuel at which successful prescribe burns can be expected (figure 20). The relationship is based on the relative amount of herbaceous fuels (grasses and forbs) and the canopy cover of big sagebrush. The relationship assumes variables fall within a prescribed range for air temperature (70 to 80° F), relative humidity (15 to 20 percent), and wind speed (8-15 mph). Shifts in this curve result with changes in air temperature, relative humidity, and wind speed. Britton and others (1981) recommend a minimum of 20 percent big sagebrush canopy cover and 200 to 300 lb/ac of herbaceous fuel to ensure prescribed fire spread. However, if cheatgrass reaches 800 to 1000 lb/ac no sagebrush canopy cover is necessary to carry fire (Britton and others 1981).

The fire spread curve presented by Britton and others (1981) appeared in the non-technical publication *Rangelands*. The authors reported on the results of three test burns to validate their relationship curve. One of the test burns, with five levels of sagebrush canopy cover verified the 20 percent minimum required canopy cover (except in the presents of cheatgrass with >800 lb/ac). In another test burn with 7 to 11 percent big sagebrush canopy cover and 500 lb /ac herbaceous fuel did not spread fire more than 30 feet despite winds of 26 mph, relative humidity at 13 percent, and an air temperature of 86° F. A test burn with 38 percent big sagebrush canopy cover and 100 lb/ac of herbaceous fuels burned with winds of 4 to 6 mph, relative humidity of 18 percent, and an air temperature of 79° F. The guidelines are useful as aids to predicting fire spread, however, they lack validation across a broad ecological range, subspecies specific verification, and rigorous statistical justification.

Figure 22—Curve representing herbaceous fuel loads and canopy cover of sagebrush at which successful prescribed burning can be expected.



Source: Britton and others 1981.

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Mechanistic Model Overview

The mechanistic systems reviewed for simulating aspects of rangeland and shrubland productivity were CENTURY, MAPSS, PHYGROW, SAVANNA, SPUR (SESPUR), COVER, and URM. Each of these models is capable of capturing herbaceous and shrubland productivity at different spatial and site complexity levels. Since COVER and URM were developed by scientists at the Intermountain Fire Sciences Lab in Missoula our review of those models was brief[10]. COVER and URM were developed for specific habitat types or species. The other models have been applied to landscapes (across sites) and for specific sites and generally include sub-models simulating hydrology, energy flow, nutrient cycling and depending on model herbivory, vegetation change, erosion, and fuel loads. PHYGROW and SPUR (SESPUR) are pont-based models using daily time steps. SAVANNA is more of a landscape model using a weekly time step. MAPSS and CENTURY were initially developed as biome or landscape models. A summary of some environmental and plant physiological parameters found to be important among the various mechanistic models is summarized in table 66. This table can be used to determine the type of information needed to model sagebrush communities.

Table 66—Ecological and plant physiological parameters important to the various simulation systems.

Parameter type	Parameter	Simulation system
Environmental	Habitat type/Ecological site	COVER[1]
	Slope	COVER[1], SPUR[2], WEPP/SPUR[6]

[10] As a major objective of this project was to review information for development of a model similar to the Forest Vegetation Simulator (FVS), we did not believe it was necessary to critical review models developed at the Fire lab.

	Aspect	COVER[1]
	Elevation	COVER[1]
	Soils/Hydrology	SPUR[2], MAPSS[3], PHYGROW[4], SAVANNA[5], WEPP*/SPUR[6]
	Climate/Precipitation	SPUR[2], MAPSS[3], PHYGROW[4], SAVANNA[5], WEPP/SPUR[6]
	Interception	SPUR[2], MAPSS[3], PHYGROW[4], SAVANNA5, WEPP/SPUR[6]
	Erosion	SPUR[2], MAPSS[3], WEPP/SPUR[6]
Autecological	Canopy area/canopy cover	SPUR[2], and also fuel/fire models Brown (1982), Frandsen (1983)
	Maximum above ground biomass	SPUR[2], PHYGROW[4], WEPP/SPUR[6]
	Leaf area index	SPUR[2], MAPSS[3], PHYGROW[4], WEPP/SPUR[6]
	Leaf to above ground biomass ratio	PHYGROW[4]; and also fuel/fire models Brown (1982), Frandsen (1983)
	Plant height	SPUR[2], WEPP/SPUR[6] and also fuel/fire models Brown (1982), Frandsen (1983)
	Maximum canopy height	PHYGROW[4]
	Stomatal conductance	MAPSS[3], SAVANNA[5]
	Root biomass	SPUR[2], WEPP/SPUR[6]
	Maximum rooting depth	PHYGROW[4]
	Root turnover rate	SAVANNA[5]
	Regeneration method	URM[7]
	Shade tolerance	URM[7]
	Seed banking	URM[7]

* WEPP Water Erosion Prediction Project is used with SPUR.
1 Moeur 1985.
2 Pierson and others 2001.
3 USDA 2005b.
4 Ranching Systems Group 2003.
5 Coughenour, M.B. No Date.
6 Spaeth and others 2004b.
7 Sutherland 2005.

A fundamental premise used in large-scale process-based biogeographic modeling is that ecosystems will grow until they reach a limiting factor such as water in temperate regions. In temperate regions fire naturally keeps the biomass below the water-based carrying capacity and therefore, it is important that disturbance processes such as fire are included in mechanistic models. Currently, several models lack an environmental disturbance submodel. COVER, PHYGROW, and SPUR all have detailed herbivory components, but lack a disturbance (i.e., fire) submodel that allows for community change. CENTURY, MAPSS, PHYGROW, and SAVANNA have fire process submodels. Of these it is clear the MAPSS system is the only one

that may capture species invasion including the conversion of sagebrush sites to pinyon-juniper as well as fire and climate change (USDA 2004); although, SAVANNA treatment of interactions between grass/shrub/tree resource competition may allow for similar conversions.

For dominant species it is likely that physiological information is available or could be estimated. Information on interactions between species, site differences, and impacts of invaders may be more difficult to determine. An overview of general information available for models is presented in tables 67-70 only to illustrate to the reader some of the large variability in describing types based on sagebrush species or subspecies. We stress this suggests a strong need to develop more site-specific information by ecological site or habitat type which will be discussed under needs. Other autecological information that may be needed for mechanistic models include sagebrush seed characteristics, including seed dispersal, seed bank, seed viability, plant age for seed production, and possibly information on heat/smoke stimulation and predation of seeds by insects, birds or rodents. Much of this information is available for many of the sage species; although, there are some disagreements about certain aspects. For example, Ziegenhagen (2004) found significant seed banking for mountain big sagebrush; whereas, others have stressed a lack of seed banking (see Johnson 2000).

Table 67—General ranges of precipitation, elevation, soil depth, and above -ground plant production for sagebrush cover types[1].

Species	Precipitation (mm)	Elevation (m)	Soil Depth	Annual Production (Kg/ha)
Mountain big sagebrush	350 – 450	1,200 – 3,200	Moderately deep	700 – 2,750
Basin big sagebrush	200 – 400	< 2,300	Deep	868 – 2,352
Threetip sagebrush	300 – 400	1,100 – 2,300	shallow to moderate	560 – 1,372
Wyoming big sagebrush	180 – 300	150 – 1,200	moderate	440 – 775
Low sagebrush	200 – 400	1,000 – 3,300	shallow	370 – 1,008
Black sagebrush	200 – 300 (400)	1,400 – 2,550	shallow	437 – 616
Stiff sagebrush	200 – 400	230 – 1,300	shallow	123 – 246

Source: Miller and Eddleman 2000.

[1] Derived from Passey and others 1982, Cronquist and others 1994, and Shiflet 1994.

Table 68—Sagebrush species fire characteristics.

Species	Fuel Load (lb/ac)	Fire Interval (years)	Post-Fire Reproduction	Post-fire Seedling Reestablishment (years)
Sand sagebrush	N/A	N/A	seed, sprouting	N/A
Basin big sagebrush	200 to 300 600 to 700	12 to 43	Seed	10 to 15
Mountain big sagebrush	N/A	15 to 50	Seed	5 to 10
Wyoming big sagebrush	N/A	10 to 70	Seed	10 to 20
Low sagebrush	100 to 600	12 to 15 10 to 90	Seed	2 to 10
Bigelow sagebrush	N/A	N/A	Seed	N/A
Silver sagebrush	260 to 900	5 to 47 (plains) 3 to 45 (mountains)	Sprouting, seed	1 to 2
Fringed sagebrush	N/A	N/A	seed, limited sprouting	3 plus
Black sagebrush	N/A	N/A	Seed	N/A
Pygmy sagebrush	N/A	N/A	Seed	N/A
Stiff sagebrush	N/A	N/A	Seed	N/A
Threetip sagebrush	N/A	N/A	Sprouting, seed,	N/A
Bud sagebrush	N/A	N/A	Seed	N/A

Table 69—Temperate climate plant parameter values for modeling species associated with big sagebrush communities.

Community description	Leaf area index	Albedo Min.	Albedo Max.	Stomatal conductance (mms^{-1})
Pseudoroegneria spicata, Poa secunda	0.7 to 1.3[1]	—	—	—
Festuca idahoensis, Pseudoroegneria spicata	1.3[1]	—	—	—
Pascopyrum smithii		—	—	8.3[2]
Artemisia tridentate	0.5[3,4]	—	—	1.0[8]
Artemisia species	—	0.37	0.44[5]	—
Semiarid grass	—	0.20	0.27[6]	—
Dry steppe	—	0.20	0.30[7]	—

Source: Breuer and others 2003.
[1] Olson and others 2000.
[2] Frank and others 1976 in Körner and others 1979.
[3] Gholz 1982.
[4] Whittaker 1966.
[5] Gates 1980.
[6] Grant and others 2000.
[7] Budyko 1974.
[8] De Puit and Caldwell 1975 in Körner and others 1979.

Table 70. Summary statistics for environmental variables associated with sagebrush species sampled in the Southern Great Basin divison of the sagebrush biome. Only sagebrush species recorded in 2 5 samples were included in the summary. Percent cover was not reported because of differences in sampling methods.

Sagebrush	n	Elevation (m)	Slope	Precipitation (cm)	Depth to Rock (cm)	Soil pH	Soil Salinity	Available water capacity (cm)
Low sagebrush	378	2,165	16	41	92	6.1	0.98	8
Alkalai sagebrush	68	1,929	12	32	103	6.0	1.31	8
Bigelow sagebrush	7	1,782	8	22	71	6.0	3.96	9

Silver sagebrush	46	2,484	11	64	120	6.4	1.07	14
Black sagebrush	1,726	1,924	11	29	101	6.3	1.81	8
Pygmy sagebrush	10	1,.819	2	25	124	7.2	2.26	11
Alpine sagebrush	7	3,126	28	85	89	51	-	7
Threetip sagebrush	13	2,025	14	42	98	6.0	1.35	10
Subalpine sagebrush	129	1,784	15	24	89	6.2	1.65	7
Basin big sagebrush	769	1,845	8	30	103	6.5	2.09	10
Monntain big sagebrush	1,518	2,274	24	50	88	6.0	0.71	9
Wyoming big sagebrush	2,521	1,832	1	29	120	6.7	2.33	11
Bud sagebrush	790	1,567	3	20	134	7.4	4.03	11

Source: Connelly and others 2004.

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GIS Models

Pinyon-Juniper Encroachment

Wisdom and others (2003) developed a GIS based model to predict pinyon-juniper encroachment into sagebrush habitats in the Great Basin and Nevada. The model was based on the earlier work of Nisbet and others (1983) in Utah to evaluate habitat quality for sage-grouse. The Nisbet model input attributes are precipitation, elevation, and radiation load index (Wisdom and others 1983). Using this logic, Wisdom and others (2003) used ecological province (based on work of West and others (1998), vegetation, elevation, proximity, precipitation, and landform to predict pinyon-juniper invasion. The following paragraphs describe the source of information for the model inputs.

The provinces are based on floristic region, soil-plant relationships, and climate that allow for discrimination of a variety of environmental gradients in basin and range topography. Although these provinces are large, encompassing millions of hectares, they provide ecological context for describing pinyon-juniper environmental relationships (Wisdom and others 2003).

Elevation is a very important predictor of pinyon-juniper invasion and these woodlands are generally located between 4,600 to 7,000 feet and are most productive from 5,000 to 7,000 feet (Wisdom and others 2003). Wright and others (1979) found the upper elevational limit of pinyon-juniper is restricted by temperature while the lower limit by precipitation. Dealy and others (1978) found the upper elevational limit of western juniper distribution in Oregon and Idaho is approximately 7,000 feet. Downslope expansion of these woodlands is more extensive than upslope expansion (Wisdom and others 2003).

Precipitation and effective moisture contribute to determining the site potential for juniper growth and production. Open stands of pinyon-juniper occurred in areas with 25 to 40 cm, while more dense stands typically receive 35 to 40 cm of precipitation (Wisdom and others 2003).

Pinyon-juniper is not often found on the valley floor (Woodbury 1947, Springfield 1976, and West and others 1978 as cited by Wisdom and others 2003). Therefore, Wisdom and others (2003) defined valley floor as having <5% slope and encompassing =40 ha.

Wisdom and others (2003) found that there was not enough specific information available to associate pinyon-juniper productivity with soil descriptions. Therefore, they use the likelihood of pinyon-juniper establishment based on existing vegetation patterns to identify communities susceptible to pinyon-juniper conversion. Pinyon-juniper establishment is most common on more mesic, cool sites with moderately deep soils. Dry sites with shallow soils exhibit slower establishment. Wet and warm sites with deep soils and cold areas with limited soil development are generally not at risk of pinyon-juniper conversion. Pinyon-juniper communities tend to be found with higher densities and establish over shorter periods of time in soils with restricted rooting depth (Wisdom and others 2003).

Proximity of sagebrush to pinyon-juniper woodland stands is a critical model component. Dispersal of pinyon pine nuts and juniper berries is facilitated by gravity, water, or animals. By gravity and water flow seed dispersal is generally limited to <2 m downslope and <1 m upslope. Nuts and berries from these species are commonly distributed =1.6 km from the parent plant by birds and mammals (Wisdom and others 2003). As a result, Wisdom and others (2003) considered all sagebrush stands within =1.6 km of pinyon-juniper, pinyon, or juniper at risk of displacement from encroachment. Sagebrush stands from >1.6 to <5 km from pinyon-juniper,

pinyon, or juniper stands were considered at risk but to a lesser degree. A stand of pinyon-juniper, pinyon, or juniper was defined as =10 ha (Wisdom and others 2003).

Pinyon-juniper is not often found on the valley floor (Woodbury 1947, Springfield 1976, and West and others 1978 as cited by Wisdom and others 2003). Therefore, Wisdom and others (2003) defined valley floor as having <5% slope and encompassing =40 ha.

The pinyon-juniper encroachment model established low, moderate, and high risk categories for encroachment. The model was programmed in Arc Macro Language and applied with ArcInfo GIS. Problems arose in the identification of pinyon-juniper stands from the land cover map. As a result, only stands located in the Central High, High Calcereous, and Bonneville ecological provinces in the eastern Great Basin were modeled (Wisdom and others 2003).

Cheatgrass Invasion

In addition to modeling pinyon-juniper encroachment, Wisdom and others (2003) used similar techniques to model the displacement of native vegetation by cheatgrass. Important attributes in predicting cheatgrass site conversion include aspect, slope, elevation, and landform. These are the same ecological provinces used for modeling pinyon-juniper invasion (Wisdom and others 2003).

Aspect was very important in prioritizing areas susceptible to displacement by cheatgrass. South-facing slopes are the most prone to cheatgrass conversion (Platt and Jackman 1946, Mosley and others 1999 as cited by Wisdom and others 2003) with greater cheatgrass mineral uptake in these energy rich environments (Wisdom and others 2003). Greater root and seed production occur on south facing slopes as compared to northern exposures. Similarly slope is

important with cheatgrass responding positively to increased insolation (Wisdom and others 2003).

In the northern ecological provinces cheatgrass was commonly found from 2,000 to 6,000 ft. while in the southern ecological provinces it was found at elevations above 4,000 ft (Wisdom and others 2003). Mack and Pyke (1983) found winter rains and discontinuous snow cover enhanced cheatgrass winter emergence. Germination is enhanced at moderate temperatures ($\sim 20^0$ C) and limited at temperatures $<10^0$ C (Wisdom and others 2003). Cheatgrass emergence, survivor, and regeneration are low at high elevations because of decreasing temperatures and length of growing season (Pierson and Mack 1990 as cited by Wisdom and others 2003).

Cheatgrass invasion occurs in valley bottoms and flat and mid-elevation landforms (Wisdom and others 2003).

The cheatgrass invasion model used three probability classes (Low, Moderate, and High) to classify the threat of understory conversion in the Great Basin. The rule-based model was programmed in the Arc Macro Language and applied in ArcInfo GIS. Cover types listed as susceptible to cheatgrass invasion included native grasslands, salt desert shrubs, sagebrush, mesic shrubs, and pinyon and juniper woodlands (Wisdom and others 2003).

The GIS rule based model for pinyon-juniper and cheatgrass invasion constructed by Wisdom and others (2003) is an effective way of creating potential site conversion risk maps. The availability of the data sets, and ease of using a GIS for this type of analysis is appealing. These models currently do not contain a time component to capture the temporal changes of these communities in terms of target species relative canopy cover. Incorporation of these rule based models into mechanistic growth and succession models has the potential of creating sound encroachment and understory conversion logic.

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Model Overview

There are many methods of representing sagebrush ecological sites and community characteristics and also models that can simulate shrub and grassland community attributes in the sagebrush biome. Fundamental modeling approaches are classified as either empirical and analytical or stochastic. Stochastic modeling systems generally have detailed successional and/or disturbance response logic and less detailed species autelogical information. In contrast, most mechanistic models for describing rangeland ecological systems provide more detailed descriptions of nutrient cycling, hydrology, and plant autecology such as rooting depth, stomatal conductance, and growth response. Empirical and analytical models are statistically driven models that often have a single, repeatable solution. In comparison, stochastic models are probabilistic with algorithms based on random choices. Of particular interest was logic describing successional patterns and disturbance response, including fire models for rangeland ecosystems and rangeland models developed using hydrologic, biogeochemistry, meteorological, and various other submodels that "grow" vegetation associated with ecosystem processes or burn vegetation (fire models). We also reviewed two GIS models that were developed to determine cheatgrass and pinyon-juniper invasion into the Great Basin. Our review of these models was for potential inclusions into other model systems for creating sound encroachment and understory conversion logic.

Stochastic landscape dynamic simulation systems (LDSS) that have been applied to a number of sagebrush biome communities include Vegetation Dynamics Development Tool (VDDT), Rocky Mountain Landscape Simulator (RMLANDS), and Simulating Vegetation Patterns and Processes at Landscape Scales (SIMPPLLE). These are "expert knowledge" based systems, as such there is considerable reliance on expert opinion and current scientific literature

to parameterize the models. These models can help in understanding of changes in vegetation over time and/or disturbance. Despite conceptual differences these models provide similar output data for a landscape. Each of these models have some drawbacks, as do all models, but a concern identified is that for managers working at the project scale level would not be provided with an "answer", but instead a range of possible outputs or probabilities of outcomes from required multiple model runs. This may not be well accepted by land managers working at the project level. The strength of these LDSS is their ability to simulate landscape level patterns and trends in community succession and disturbance response and provide for an understanding of potential changes across the landscape.

In contrast, empirical and analytical systems simulate detailed mechanistic processes at different spatial and temporal scales. The mechanistic systems we reviewed dealing with grassland or shrubland productivity were CENTURY, MAPSS, PHYGROW, SAVANNA, SPUR (SESPUR), COVER, and URM. The COVER and URM models were developed for specific habitat types or species; whereas, the other models have been applied to landscapes (across sites) and for specific sites and include submodels simulating hydrology, energy flow, nutrient cycling and other attributes such as herbivory, vegetation change, erosion, and fuel loads. All of these mechanistic systems have inherent strengths and weaknesses, but in general all are data intensive. These empirical systems assume there is sufficient knowledge to model the various aspects in which the model was developed to simulate; for example, individual plant growth, mortality and reproduction across variable climatic regimes, soil types and disturbance inputs. For dominant species it is likely that physiological information is available or could be estimated. Information on interactions between species, site differences, and impacts of invaders may be more difficult to determine. Numerous fire spread and behviour model also exist, but all

the the fuel model are still based on the assumptions of homogeneous and continuous fuels: seldom the case in the semi-arid sagebrush communities.

Others have taken a different approach to modeling sagebrush biome vegetation and vegetation change. For example, by identifying the appropriate environmental variables influencing sagebrush invasion by pinyon-juniper, Wisdom and others (2003) were able to develop risk maps of sagebrush conversion to woodland types using GIS rule-based predictive models. Athough Wisdom and others (2003) identified a number of concerns regarding the results of their GIS models, their approach may be useful for creating encroachment and understory conversion logic into mechanistic models.

In summary, a number of modeling systems exist that have been used in sagebrush or similar ecosystems to answer a number of questions. All of the reviewed models have advantages and disadvantages and we are reluctant to suggest the "best" modeling approach. However, we suggest that the type of model needed is one that will capture vegetation biomass or energy capture (annually and possibly interannually), fuel loading, biogeochemistry (nutrients for growing plants), climate, hydrology, species invasions, succession, fire, and grazing. At this time it seems that a combination of approaches may need to be developed to ensure the type of model needed. As a primary impetus of this project was to determine if a Rangeland Vegetation Simulator (RVS) could be developed for sagebrush communities we will discuss model needs in the following section "*Sagebrush Biome Overview and Research Needs*".

SAGEBRUSH BIOME OVERVIEW AND RESEARCH NEEDS

Sagebrush and sagebrush habitats have received considerable interest because of their values and areal extent. As such, there considerable autecological information on many of the

species; however, our understanding of synecological relationships, especially with the introduction of exotic species and changes in climate, is much more limited. We are aware that sprouting sagebrush species recover quickly after fire and are often early seral species, but non-sprouters, the majority of sagebrush shrubs, may take considerable time to recover with large differences in species and subspecies. Cheatgrass and other exotic annuals change the fire regime by increasing fine fuel loading (Hironaka 1991, Whisenant 1990). If annuals are present in pre-fire communities the probability of community changes following fire are high. In more mesic sagebrush types, changes from shrubland to woodland or forest with conifer encroachement are a result of decreased fire frequencies. These woodlands and forests are susceptible to crown fires and the intensity of fires may have dramatic consequences on these sites (Miller and Rose 1995, 1999, Miller and Tausch 2001, Bunting and others 2002).

In order to model sagebrush habitats the type of information needed will be dependent on objectives of the models and scales in which the models are developed for use. We suggest that it is critical to understand what plant associations or ecological sites are susceptible to exotic plant invasion, and to what degree, and to understand mechanisms of reducing invasions. In the following sections we provide a summary of current information available for modeling these sagebrush types and discuss needs.

Modeling Sagebrush Landscapes: Information Needs

In order to model the sagebrush biome across landscapes information on the current vegetation type, potential vegetation types (historical plant community and seral communities or states), fuel loads, disturbance probabilities, and time factors for changes in community structure (succession) will be needed. We believe the amount of information on current plant

communities (structure and composition) across much of our sagebrush landscapes is very limited. Some general information is available from National Gap Analysis Program[11] (http://www.gap.uidaho.edu/), but that information is of limited use for modeling specific community attributes across the landscape. Public land management agencies such as the Bureau of Land Management, Forest Service, and various State lands departments, will have some data on rangeland types, but the cost of keeping this information current is too costly for agencies to have very current plant community (composition and structure) information. Plant cover information from the LandFire (http://www.landfire.gov/) program maybe more current than GAP cover types, but is still quite general and possibly not available.

Ecological site information to better define sites, pathways, disturbances, and states regarding sagebrush types is needed for modeling dynamics of sagebrush communities. It appears that information on cover types or vegetation states and historic plant communities for sites are available from a number of sources. All western states developed range site information associated with MRLAs (Major Resource Land Areas). The MRLA's for Idaho are shown in Appendix L. The range sites were determined from soils, landscape settings, precipitation zone and plant growth limiting factors and a total of 385 sites were found in Idaho with 257 of these sites having sagebrush listed in the community composition (Appendix M). Range sites provide a description of the plant association and productivity but not structure (height or cover), fuel loads, or alternate vegetation states.

McAdoo and others (2003) recommend establishing state-and-transition models for sagebrush communities to clearly identify ecological thresholds and possible transitions at earlier

[11] The land cover types for Nevada's GAP analysis is presented in Appendix K

stages to prevent irreversible site damage as the result of management actions. For Oregon and Nevada ecological site descriptions have been developed which may provide modelers with better potential vegetation type information and pathways that could be used for modeling succession using state and transition models. The ecological site descriptions also provide information on invasive species, production and variability associated with "good to bad" years, but like range sites do not provide information on structure (height and cover) or fuel loads. Oregon ecological sites of the Central Rocky and Blue Mountain Pumice Zone (Major Resource Land Area (MRLA) B10A are presented in Appendix N. Oregon ecological site descriptions available from NRCS web site (http://www.or.nrcs.usda.gov/) and an example of an ecological site description for Oregon is presented in Appendix O. Appendix P shows the *Artemisia* dominated natural vegetation types of Oregon (Kagan and others 2004) and provides sources for the development of the natural vegetation type. As stated previously, the sources of information for the development of these natural vegetation types shows each type is based on very few sources, with some based only on unpublished information.

The development of ecological site descriptions and the state and transition models for western states will provide succession information for modeling of these types. Also, the LandFire program through The Nature Conservancy is developing state-and-transition models for the U.S. These state and transition models have information on states, time for transitions, fire probabilities, and other potential disturbance pathways. This will be an additional source of information for development of states for different sagebrush types, but we stress again research to base these states on is very limited. Throughout this report (and in the appendices) we have included data from various studies that summarize information availavle for model development. In tables 67-70 we include a number of tables as summary tables to illustrate some of the large

variability in examining site conditions by species or subspecies. Again, we suggest this implies a strong need to develop more site-specific information.

Modeling Sagebrush Landscapes: Models Reviewed and Needs

Several stochastic landscape dynamic simulation systems (LDSS) that represent a limited number of sagebrush biome communities include Vegetation Dynamics Development Tool (VDDT) (Beukema and others 2003), and Rocky Mountain Landscape Simulator (RMLANDS) (McGarigal and others No Date), and Simulating Vegetation Patterns and Processes at Landscape Scales (SIMPPLLE) (Chew and others 2003). These systems are "expert knowledge" based systems and as such there is considerable reliance on expert opinion and current scientific literature to parameterize the models (McGarigal and others No Date, Baker 1989). The strength of these LDSS such as SIMPPLLE is their ability to simulate landscape level patterns and trends in community succession and disturbance response (Chew and others 2004). However, these systems are not able to capture highly detailed mechanistic processes often specific for a vegetative stand.

Land managers would benefit from models that captured highly detailed mechanistic processes for a sagebrush stand to predict changes associated with disturbance. The Forest Vegetation Simulator is one such model, but contains information probably not relevant for most sagebrush sites, and perhaps misses information that is needed: for example, grazing and weed invasion. We discuss the data needed for the FVS in this section and relate those data needs to a RVS as the development of a sagebrush biome model similar to FVS was one impetus of this project.

The base data needs for the Forest Vegetation Simulator are site conditions (slope, aspect, elevation, habitat type or plant association, location, site index, stand density index maximums or basal area maximums), inventory information (procedures of collecting information), and tree characteristics (species, dbh, height, crown ratio, and other information). Sagebrush site information such as slope, aspect, and elevation are either available as GIS coverage or could be developed. As stated in the previous section, information on habitat type and plant associations are limited; however, ecological sites could be used in place of habitat types if ecological site information is developed. Information on productivity (a site index) is available with ecological site or range site information. Data on structure (height and cover) and fuel loads are not available in ecological site guides or range site descriptions. It is also true that much of the data generated from the Forest Inventory and Analysis (FIA) Program of the U.S. Department of Agriculture (USDA) Forest Service and used in FVS is much more detailed (spatially and temporally) than information currently being collected on rangelands.

COVER is an extension of the Prognosis model and describes the amount of cover and foliage in the tree canopy by height class, the height and cover of shrubs, forbs, and grasses in the understory, and a summary of overstory and understory cover and biomass for a stand in the FVS. A concern for developing a similar model is the lack of information on cover and height of plant species found in the many ecological sites or habitat types. For the most part, data regarding annual production is more common than coverage or height data. A few sources of height and coverage data are available and likely there are administrative studies with this type of data. For example, Blaisdell (1958) reported on both leaf and flower stalk heights of bluebunch wheatgrass and arrowleaf balsamroot in the Snake River Plains of Idaho and reported considerable variation during a 16 year period (Appendix Q). He did not report data on cover.

Cover and height data could also be developed for ecological sites using "expert knowledge" or measured across sites using various means, including high resolution remote sensing procedures.

The shrub subcomponent of COVER is calibrated from over 10,000 1/300-acre forest plots in northern Idaho, northeastern Washington, and northwestern Montana, central and southern Idaho, and northwestern Wyoming (Moeur 1985). Thus, the focus of this extension was not the sagebrush biome. As stated previously, ecological site information does not include structural information (height or cover), and therefore this will limit the ability of using a model like COVER. In COVER, the probability of shrub occurrence in the stand and total shrub cover are based on the work of Laursen (1984), while the probability of individual species occurrence is based on the logistic multiple regression work of Scharosch (1984) (based on 10,000 plots located in 500 stands) (Moeur 1985). Twig production and dormant season shrub biomass are predicted for three habitat types and is based on the work of Irwin and Peek (1979). We did not find studies like those of Laursen (1984) and Scharosch (1984) for sagebrush types. We suggest that for the development of a COVER subcomponent for a sagebrush RVS there would be a strong need for studies like Laursen (1984) and Scharosch (1984) in sagebrush habitat types or cover types. However, it may also be feasible to use mechanistic models to "grow" plants and communities.

The Fire and Fuels Extension to the Forest Vegetation Simulator (FFE-FVS) links the existing FVS, models that represent fire and fire-effects, with newly developed fuels dynamics and crowning sub-models. A number of fuel models exist for sagebrush types (see section on Fire Models) and similar models could be developed to show dynamics with different fire scenarios. In much of the previous work dealing with fire models in sagebrush types there has been a concern of non-continuous fuels associated with these systems. For most of the sagebrush

biome, fires will be stand replacement fires where fuel loads allow fires to burn stands (often fires will not be continuous because of low fuel loading). Where cheatgrass or other exotic annuals occur there is an increase in coverage of fine fuels that have resulted in increased fire frequencies. In modeling sagebrush communities the threat of exotic invaders must be considered as well as the potential impact of reduced fires and conversion to woodlands or forests and added fuels to the systems.

It was quite difficult to determine if mechanistic models such as PHYGROW, SPUR and SESPUR, SAVANNA, MAPSS, and CENTURY would simulate sagebrush biome processes desired for a RVS (including accuracy as little information was available testing models and most tests did not seem that promising). PHYGROW and SPUR are point based, daily time step models that simulates above ground plant growth, forage consumption, and hydrologic processes. The SAVANNA model operates on a weekly time step and simulates processes at landscape through regional scales on an annual or decadal scale. MAPSS and CENTURY were developed initially as landscape to biosphere feedback models and CENTURY has a monthly time step. As such, these models seem less able to extract the some types of information that would be desired for a RVS, as compared with PHYGROW, SPUR, and SAVANNA. Other limitations and advantages of these models were previously discussed in the "Mechanic Simulation Systems" section. PHYGROW, SPUR, and SAVANNA all need detailed species parameters for physiological aspects and these models are very data intensive. It is also unclear how these mechanistic models would deal with community change associated with fire and exotic plant invasion.

Modeling Sagebrush Landscapes: Summary and Conclusions

To develop models to aid our understanding of the sagebrush biome we need to increase our knowledge of the historic and current conditions and develop predictions of future conditions under different management or disturbance scenarios. An understanding of historic conditions is necessary to determine the range of variability of these types over the landscape and thus to predict what should be present across landscapes. Prior to European settlement, fire played a major role in the ecosystems of the Intermountain West (Wright and Bailey 1982, Miller and others 1994) by creating a mosaic of seral conditions across a variety of plant cover types. In the last 150 years, fire regimes in the mountain big sagebrush *(Artemisia tridentata vaseyana)* alliance have been altered, burning less frequently and more intensely (Houston 1973, Burkhardt and Tisdale 1976, Miller and Wigand 1994, Miller and others 1994, Miller and Rose 1999, Miller and Tausch 2001); whereas, in much of the Wyoming big sage brush alliance (*Artemisia tridentata wyomingsis*) the fire frequency has increased as a result of the invasion of exotic annuals, especially cheatgrass.

In this study we reviewed literature on the sagebrush biome. Initially, we reviewed the dominant sagebrush species and provide a summary of autecological and synecological information on these species to aid those in developing models. We reviewed the threats on the sagebrush biome as the basis for the need to model plant community change. We reviewed a number of stochastic, mechanistic, GIS, and fuel models that have been applied to modeling plant communities in sagebrush types. Because of the amount of information, and for the most part the general nature of the information, our document is also a general overview of this information. We found that there is a lack of site specific information on plant community development that we believe is needed to develop specific mechanistic models to inform land managers the consequence of treatments. With that said, it also seems that it is time to begin

model development to better determine data needs. Developing a model for the sagebrush biome is possible, but the type of model will drive the type of information that is needed. As the landscape area to be modeled becomes larger (such as biome versus habitat type or ecological site) our level of understanding and our ability to predict changes on a plot scale decreases.

A number of factors have been identified that threaten the sagebrush biome. These include overgrazing, changes in fire frequency, change in climate, exotic plant invasion, changes in plant community type (shrub to forest or woodland or shrub to annual communities), agriculture conversion, mining, road construction and urban development. There is little doubt that we do not fully understand all of the interactions between these factors (for example, change in climate on exotic plant invasion). Threats such as overgrazing by livestock, agriculture conversion, and urban development are generally more localized. These are threats that land managers may mitigate, but mitigation is very difficult when managers are also dealing with exotic plant invasion, type conversion, and changes in fire frequency, and the largely unknown impacts of climate change. It is clear that land managers and policy makers need a better understanding of the consequences of these changes on our ecosystems. The lack of information on the rates and variability of natural post-fire recovery and treatments to ensure maintenance of multiple-use values limits the ability of managers to develop long-term fire programs and manage sagebrush cover on a landscape level. The need to understand and model changes the sagebrush biome is associated with three important aspects:

1) The large extent of the sagebrush biome. The sagebrush (*Artemisia*)-grasslands comprise the largest rangeland vegetation biome in western North America and sagebrush taxa occur on 109 million ha (Beetle 1960; McArthur and Plummer 1978 from Wambolt 2001) and sagebrush vegetation types in the western U.S. are estimated to cover 58 million ha (Branson and others 1967) to 63 million ha (West 1983 a and b).

2) The number of species dependent on the sagebrush communities and are currently species of concern. These include sage grouse, Brewer's sparrow, sage thrashers, and pygmy rabbits. However, other species benefit greatly from sagebrush communities and many of these species are considered to be declining in parts of the Great Basin (Bureau of Land Management, 1999, Appendix R). Such threats may translate into risks to various species and their habitats. For example, in a recent summary of risks to biodiversity among each of the 50 United States, Stein (2002) reported that Utah was ranked 3rd and Nevada 4th for plants at risk. The Great Basin Shrub Steppe Ecoregion, as defined by WWF-US, was reported as having only 5-9% of its remaining habitat intact (Ricketts and others 1999).
3) The impact of changes carbon sequestration and soils, and possible influences on climate, and in general on other values.

To determine changes in plant communities the minimum requirements would be a knowledge of the potential (habitat type or ecological site), current conditions, including the current plant community, grazing use, etc, and successional stages (trajectories, ages, and probabilities of seral stages. In addition to this information, we also need physiological information including seed production, plant establishment, longevity, and growth rates, hydrological information, fuel loads, grazing response and an understanding of the response of the communities to disturbance factors to develop sound mechanistic models. The potential plant community (habitat type, range site, or ecological site) is available predominately associated with soil mapping by the NRCS. The NRCS is currently developing more detailed plant community information for ecological sites using state-and-transition models. Some western States (such as Nevada and Oregon) have published this information, but for Montana, Idaho, and Utah only range site information is available. At the current time the ecological sites are not available spatially.

For both range sites and ecological sites there is an estimate of potential plant community composition on a weight basis (current annual production) and a range in productivity, but often this information is based on very few sites. There is no information on fuel loading, height, or cover in these site descriptions. As stated previously, either range site or ecological site information will provide some data on potential communities and thus some information on productivity and probability of occurrence of species. However, the potential plant community provides no information on current conditions or plant communities. Ecological site information will provide information on potential states but does not provide information on the current plant community found on the site. The lack of information on current plant communities is problematic for modeling change across the landscape because of the importance of the initial floristics on change.

We suggest there is a strong need for a Rangeland Vegetation Simulator (RVS) because a decision support system should greatly aid land managers in managing these types. Appendices S and T are simple flow diagrams illustrating how complex decisions quicky get for two sagebrush types considering only a few questions. As previously mentioned sagebrush habitats are threatened by overgrazing, exotic plant invasion, altered fire regimes, climate change, mining, roads, and conversion to agricultural lands and urban areas. These wildlands provide numerous products and values to humans and without a concerted effort to better understand these systems we will continually lose more of these habitats across the western U.S. There is no doubt that there are "holes" in our knowledge base and that no current model meets all of our needs. The development of the RVS will illustrate subject areas where knowledge gaps emerge in the decision support process and a need for research. Therefore, we propose that the construction of a model would include a suite of information technologies capable of supporting

decision making by policy makers, resource managers and students as it concerns natural resource management issues. The development of RVS should be considered an interdisciplinary approach that links applied field research, with decision support systems, and policy biophysical models to aid decision makers in natural resource management and policy formulation.

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APPENDICIES

Appendix A—Sagebrush species and subspecies general distribution and site characteristics[1].

Species	Subspecies	Distribution and site characteristics
Low sagebrush (*A. arbuscula*)	Low sagebrush (*arbuscula*)	W. Wyoming to S.C. Washingon and N. California on dry, sterile, rocky, shallow, alkaline, clay soils.
	Cleftleaf sagebrush (*thermopola*)	W. Wyoming, N. Utah, and E. Idaho on spring-flooded, summer-dry soils.
	Lahontan sagebrush (*longicaulis*)	N.W. Nevada extending into adjacent California and Oregon on soils of low water-holding capacity and shallow depth, usually around and above the old shoreline of Lake Lahontan.
Bigelow sagebrush (*A. bigelovii*)		Four Corners area extending to N.E. Utah, S.E. California, and W. Texas on rocky, sandy soils.
Silver sagebrush (*A. cana*)	Bolander silver sagebrush (*bolanderi*)	E. Oregon, W. Nevada, and N. California on alkaline basins.
	Plains silver sagebrush (*cana*)	Generally E. of Continental Divide, Alberta and Manitoba to Colorado on loamy to sandy soils of river bottoms
	Mountain silver sagebrush (*viscidula*)	Generally W. of Continental Divide, Montana and Oregon to Arizona and New Mexico in mountain areas along streams and in areas of heavy snowpack.
Alkali sagebrush (*A. longiloba*)		S.W. Montana, N.W. Colorado, W. Wyoming, N. Utah, S. Idaho, N. Nevada, and E. Oregon on heavy soils derived from alkaline shales or on lighter, limey soils.
Black sagebrush (*A. nova*)	Duchesne black sagebrush (*duchesnicola*)[2]	Uinta Basin, Utah, in reddish clay soil uplands.
	Black sagebrush (*nova*)	S.E. Oregon and S.C. Montana to S. California and N.W. New Mexico on dry, shallow, stony soils, with some affinity for calcareous conditions.
Pygmy sagebrush (*A. pygmaea*)		C. Nevada and N.E. Utah to N. Arizona on desert calcareous soils.
Stiff sagebrush		E. Oregon, E. Washington, and W.C. Idaho on

Species	Subspecies	Distribution and site characteristics
(*A. rigida*)		rocky scablands.
Rothrock sagebrush (*A. rothrockii*)		California and Nevada in deep soils along the forest margins of the Sierra Nevada and outliers.
Big sagebrush (*A. tridentata*)	Snowbank big sagebrush (*spiciformis*)	Wyoming, Idaho, Colorado, and Utah in high mountains.
	Basin big sagebrush (*tridentata*)	British Columbia and Montana to New Mexico and Baja California in dry, deep, well-drained soils on plains, valleys, and foothills.
	Mountain big sagebrush (*vaseyana*)	British Columbia and Montana to Baja California in dry, deep, well-drained soils on foothills and mountains.
	Wyoming big sagebrush (*wyomingensis*)	North Dakota and Washington to Arizona and New Mexico in poor shallow soils often underlain by a caliche or silica layer.
	Xeric big sagebrush (*xericensis*)	W.C. Idaho on basaltic and granitic soils.
Threetip sagebrush (*A. tripartita*)	Wyoming threetip sagebrush (*rupicola*)	Wyoming on rocky hills.
	Tall threetip sagebrush (*tripartite*)	E. Washington and W. Montana to N. Nevada and N. Utah on moderate-to-deep well-drained soils

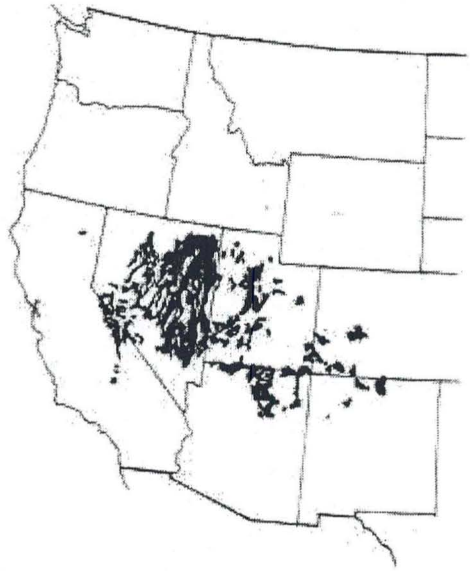
Source: McArthur 2000.

[1] After McArthur 1994 with additions from Winward and McArthur 1995 and Welsh and Goodrich 1995 as cited in McArthur 2000.

[2] Described at the variety level by Welsh and Goodrich (1995) but analogous to the other subspecies listed in the table.

Appendix B. Map of the Great Basin-Colorado Plateau sagebrush semi-desert ecosystem.

From: est, N.E. 1983a. Great Basin-Colorado Plateau Sagebrush Semi-desert. Pages 331-349 in N.E. West editor. Temperate deserts and semi-deserts. Elsevier Science, Amsterdam, The Netherlands.



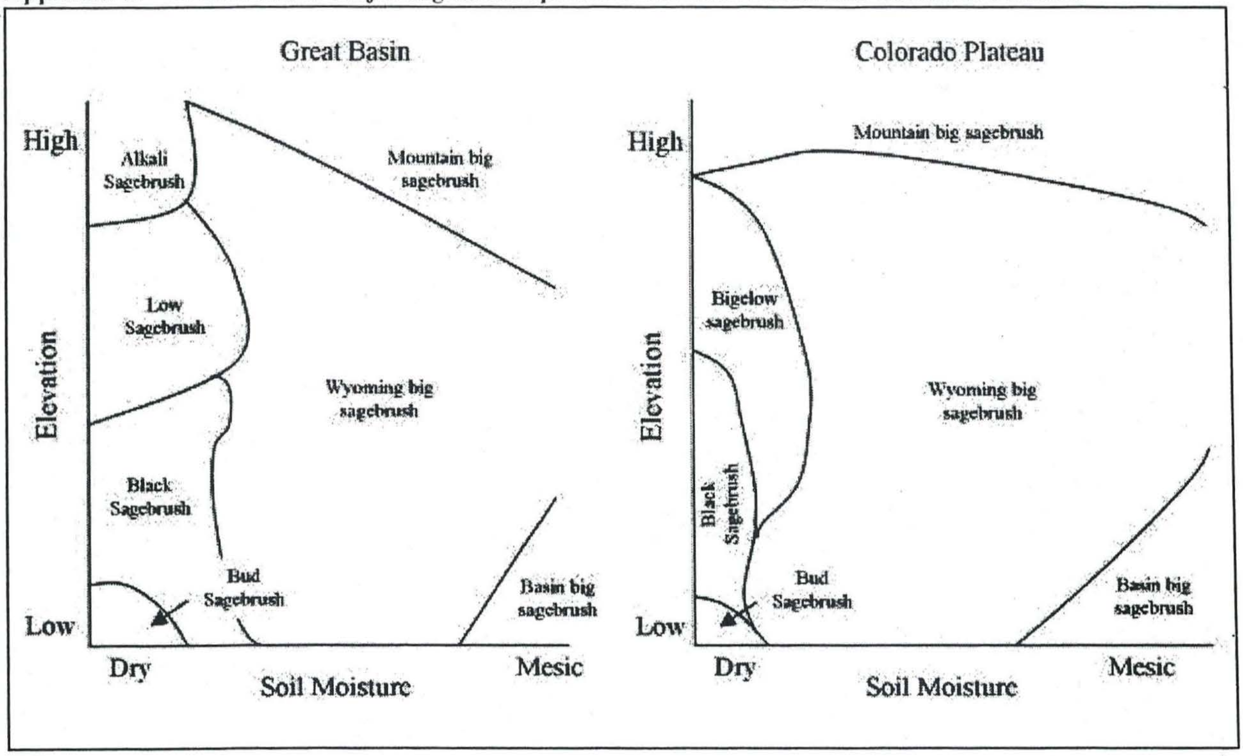
State	Area	Percentage of
Nevada	10.6	59.2
Utah	2.7	15.1
Arizona	2.4	13.5
Colorado	0.9	5.1
California	0.8	4.4
New Mexico	0.5	2.7
Total	17.9	100.0

Appendix C. Area of western United States occupied by sagebrush steppes.

From: West, N.E. 1983b. Intermountain Sagebrush Steppe. Pages 351-374 *in* N.E. West editor. Temperate deserts and semi-deserts. Elsevier Science, Amsterdam, The Netherlands).

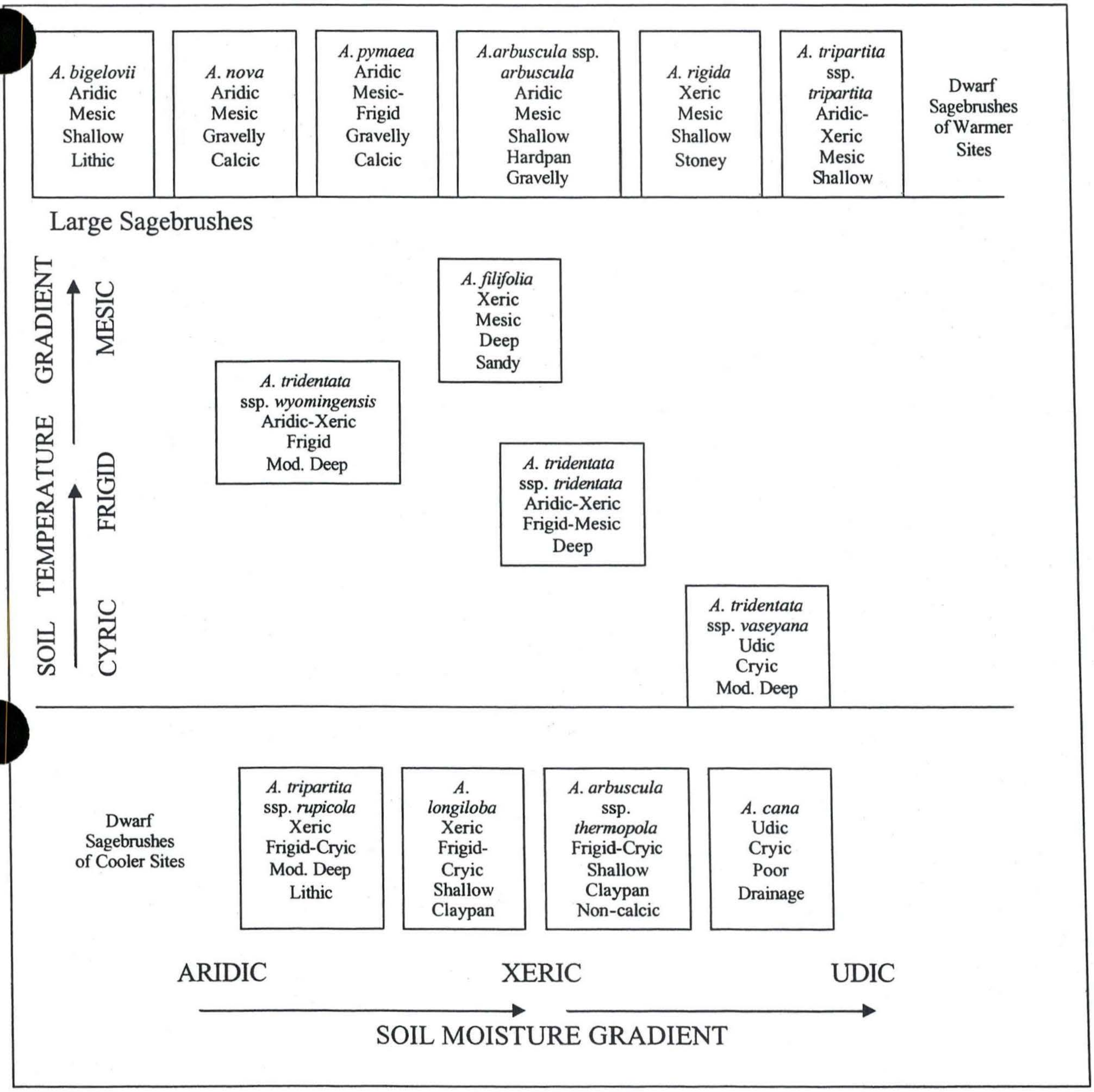
State	Area (million ha)	Percentage of total area
Wyoming	10.9	24.3
Idaho	10.3	22.9
Oregon	9.2	20.5
Nevada	4.7	10.6
Washington	3.8	8.5
California	1.8	4.1
Colorado	1.7	3.8
Montana	1.3	2.9
Utah	1.1	2.4
Total	44.8	100.0

Appendix D—Ordination of major sagebrush species in the Great Basin and Colorado Plateau.



Source: West 1979 as cited by West 1983.

Appendix E—Ordination of Intermountain sagebrush species[1].



Source: Connelly and others 2004.

[1] Adapted from West and Young 2002, with additions from Roberston and others 1966, and McArthur 1983 as cited by Connelly and others 2004.

Appendix F—Sagebrush potential vegetation types (PVT) and primary disturbance factor for the Interior Columbia Basin.

Potential vegetation type (PVT)	Prior habitat type classification	Site characteristics	Stages of community alteration	Fire characteristics
Salt desert shrub	*Sarcobatus vermiculatus/Distichlis stricta*[1] *Grayia spinosa Poa secunda*[1] *Eurotia lanata/Poa secunda*[1] *Sarcobatus vermiculatus/Pascopyrum smithii*[2] *Sarcobatus vermiculatus/Elymus cinereus*[2]	Poorly drained flats or basins with saline soils in mosaic with Wyoming big sagebrush-warm PVT (<6,500 ft. and receives <12 inches precipitation)	**Slightly altered:** intact shrub component and low cover of invasive annuals. **Severely altered:** shrub and half-shrub component is replaced by invasive annuals.	Slightly altered sites are unlikely to burn due to low fine fuel loads except after periods of above-normal precipitation (Knight 1994, Pellant and Reichert 1984). After fire invasive annual increase greatly, increasing the probability of subsequent fires. Frequent fires may inhibit the establishment of native shrubs and increase the area of disturbance. Fire often starts in adjacent Wyoming big sagebrush-warm PVT and spreads to this type.
Wyoming big sagebrush-warm	*Artemisia tridentata/Pseudoroegneria spicata*[1] *Artemisia tridentata* ssp. *wyomingensis/Poa secunda*[3] *A. t.* ssp. *wyomingensis/Elymus elymoides*[3] *A. t.* ssp. *wyomingensis/Achnatherum thurberianum*[3] *A. t.* ssp. *wyomingensis/Pseudoroegneria spicata*[3] *A. t.* ssp. *wyomingensis/Hesperostipa comata*[3]	Occupies lower elevation (<6,500 ft.) and more arid (<12 inches precipitation) sites. Common on semiarid valley bottoms and lower mountain slopes.	**Slightly altered:** Shrub overstory is intact with the understory modified by livestock grazing and invasive plants. Cheatgrass (mod. to light textured soils) and medusahead (heavier textured soils) (Dahl and Tisdale 1975). **Severely altered:** Sites are dominated by invasive annuals. Altered fire intervals and the removal of native species seed sources may make these changes irreversible (Young and others 1979).	Severely altered sites now burn on a 5 year interval as opposed to the historic 50 to 100 year interval (Whisenant 1990). Frequent fire has depleted sagebrush and fire-sensitive herbaceous species; removing the seed source. Soils have eroded or been modified.
Wyoming big sagebrush-cool	*Artemisia tridentata/Festuca idahoensis*[1]	Higher elevation (>3,300 ft.) and colder	**Slightly altered:** Invasive annuals do not influence this type to the	Wildfire intervals on slightly altered sites have

Potential vegetation type (PVT)	Prior habitat type classification	Site characteristics	Stages of community alteration	Fire characteristics
	Artemisia tridentata/Pseudoroegneria spicata[2] *Artemisia tridentata* ssp. *wyomingensis/Poa secunda*[3] *A. t.* ssp. *wyomingensis/ Elymus elymoides*[3] *A. t.* ssp. *wyomingensis/Achnatherum thurberianum*[3] *A. t.* ssp. *wyomingensis/Pseudoroegneria spicata*[3]	sites. Colder winter temperatures limit annual grass influences. Occurring in valley bottoms and lower slopes.	same degree as the warm phase due to increased precipitation and cooler temperatures. The shrub component is intact and while invasive plants are present, native perennials occupy the site. Sites respond to management changes (Eckert and Spencer 1986, Wambolt and Payne 1986, Yeo and others 1990) but native species are slow to recover. **Severely altered:** Understory canopy deplete of native perennials are severely altered. Reestablishment of native species is slow.	not increased as greatly as in the warm phase of this PVT. In severely altered communities wildfire is uncommon due to the lack of fine fuels. When fire occurs, however, it results in an early seral community of native and invasive species. Shrub reestablishment and site recovery may take decades (Eckert and Spencer 1986, Harniss and Murray 1973).
Basin big sage brush	*Artemisia tridentata/Pseudoroegneria spicata*[1] *Artemisia tridentata* ssp. *tridentata/Pseudoroegneria spicata*[3] *A. t. tridentata/ Hesperostipa comata*[3]	Lower elevation sites with deep soils. Found in mosaics with Wyoming big sagebrush-warm PVT. Shrub structure is 1 to 3 m tall depending on shrub age and soil productivity.	Most of this PVT has been converted to intensive agriculture (Hironaka and others 1983) or influenced by grazing and invasive species. This PVT often occurs in mosaic with Wyoming big sagebrush-warm PVT and suffers from the same species conversion and fire interval alteration.	Fire often starts in adjacent Wyoming big sagebrush-warm PVT and spreads into this PVT. Severely altered sites now burn on a 5 year interval as opposed to the historic 50 to 100 year interval (Whisenant 1990). Frequent fire has depleted sagebrush and fire-sensitive herbaceous species; removing the seed source. Soils have eroded or been modified.
Threetip sagebrush	*Artemisia tripartita/Pseudoroegneria spicata*[1,3] *Artemisia tripartita/Festuca idahoensis*[1,2,3]	Widespread distribution but seldom locally abundant. Occurring with Wyoming big sagebrush but often on north and east slopes.	**Slightly altered:** The shrub component is intact and native perennials dominate the understory. Livestock grazing is the primary disturbance factor. These sites, often in the Idaho fescue	This resprouting species is more resistant to fire than other sagebrush species (Beetle 1960, Morris and others 1976) and may increase following fire

Potential vegetation type (PVT)	Prior habitat type classification	Site characteristics	Stages of community alteration	Fire characteristics
			environmental range, respond well to management. **Severely altered:** The majority of these sites are within the bluebunch wheatgrass environmental range. The shrub overstory is intact but native perennial canopy cover is depleted. Cheatgrass is not often invasive in this type (Hironaka and others 1983).	(Bunting and others 1987). Frequent fires occur in this PVT when invasive annuals are present.
Low sagebrush-xeric	*Krascheninnikovia lanata/Poa secunda*[1] *Krascheninnikovia lanata/Artemisia tridentata* ssp. *wyomingensis*[4] *Atriplex falcate/Artemisia tridentata* ssp. *wyomingensis*[4]	Dominated by winterfat (*Krascheninnikovia lanata*), and in fine scale mosaics with Wyoming big sagebrush, species distribution depends on soil salinity (Knight 1994).	**Slightly altered:** The shrub layer is relatively intact with reductions in winterfat, nuttall saltbush, and biological soil crust resulting from past grazing. As winterfat decreases with an increase of livestock disturbance, invasive annuals increase as well. **Severely altered:** The shrub component is missing, due to frequent fire and understory conversion to cheatgrass and other invasive annual species.	Winterfat dominated sites normally do not support fire readily (Pellant and Reichert 1984), however, with more than 1 year of above-average precipitation, and the presence of cheatgrass, fine fuel loads may support fire. Following the initial fire in these PVT winterfat and other shrubs are replaced by invasive annual species.
Low sagebrush-mesic (Low, stiff, and little sagebrush species)	*Artemisia rigida/Poa secunda*[1,3,6] *Artemisia arbuscula/ Achnatherum thurberianum*[5] *Artemisia arbuscula-Purshia tridentata/Pseudoroegneria spicata*[5] *Artemisia arbuscula/Pseudoroegneria spicata*[2,3] *Artemisia arbuscula/Festuca idahoensis*[2,3,5] *Artemisia arbuscula/Poa secunda*[3] *Artemisia longiloba/Festuca idahoensis*[3,5]	These sites are dominated by low, stiff, black, or other low sagebrush spp. Distinctive soils separate these sites from those supporting big sagebrush PVT. Herbaceous cover and production is less than surrounding PVT.	**Slightly altered:** Improper grazing has caused reduction and displacement of species. These sites do respond quickly to management changes if seed sources are available. **Severely altered:** Native perennial cover is greatly reduced and invasive species are present. Large areas of stiff sagebrush have been invaded by cheatgrass.	Fire is limited in this PVT due to the sparse herbaceous cover. Recovery is slow following fire. Fire often originates in adjacent Wyoming big sagebrush-warm PVT that has an invasive annual understory.

Potential vegetation type (PVT)	Prior habitat type classification	Site characteristics	Stages of community alteration	Fire characteristics
	Artemisia nova/Pseudoroegneria spicata[3,5] *Artemisia nova/ Pseudoroegneria spicata* ssp. *inerme*[5] *Artemisia nova/Festuca idahoensis*[3] *Artemisia nova/ Hesperostipa comata*[5]			
Low sagebrush-mesic with juniper	*Artemisia arbuscula/ Achnatherum thurberianum*[5] *Artemisia arbuscula-Purshia tridentata/Pseudoroegneria spicata*[5] *Artemisia arbuscula/Pseudoroegneria spicata*[3] *Artemisia arbuscula/Festuca idahoensis*[3,5] *Artemisia arbuscula/Poa secunda*[3] *Artemisia longiloba/Festuca idahoensis*[3,5] *Artemisia nova/Pseudoroegneria spicata*[3,5] *Artemisia nova/ Pseudoroegneria spicata* ssp. *inerme*[5] *Artemisia nova/ Hesperostipa comata*[5]	Juniper woodlands occur in mosaic with low sagebrush-mesic sites.	**Slightly altered:** Improper grazing has caused reduction and displacement of species. These sites do respond quickly to management changes if seed sources are available. **Severely altered:** Native perennial cover is greatly reduced, while juniper cover has increased.	Fire is historically infrequent in this PVT, however, with fire suppression and the removal of fine fuels by grazing juniper establishment and growth has increased in the last 150 year (Miller and Rose 1999, Miller and Wigand 1994). The lack of fine fuels in severely altered sites makes fire unlikely.
Mountain big sagebrush-mesic east	*Artemisia tridentata* (ssp. *vaseyana*)/*Festuca idahoensis*[2,3] *A. t* .(ssp. *vaseyana*)/*Festuca campestris*[2] *A. t.* ssp. *vaseyana/Pseudoroegneria spicata*[3] *A. t.* ssp. *vaseyana/Festuca idahoensis*[3] *A. t.* ssp. *vaseyana-Symphoricarpos oreophilus/Pseudoroegneria spicata*[3] *A. t.* ssp. *vaseyana-Symphoricarpos*	This PVT occupies valley bottoms and mountain slopes.	**Slightly altered:** Past grazing and fire suppression have allowed shrub cover to increase, while herbaceous cover decreases. In addition, invasive annuals are present in this PVT but do not influence the disturbance and community dynamics as in other types. **Severely altered:** Native herbaceous cover is greatly reduced.	Historically, much of this PVT had shorter fire intervals (Arno and Gruell 1983, Bunting and others 1987, Houston 1973). As a result of fire suppression and fine fuel reduction from grazing, sagebrush cover has increased, while herbaceous cover decreased.

Potential vegetation type (PVT)	Prior habitat type classification	Site characteristics	Stages of community alteration	Fire characteristics
	oreophilus/Festuca idahoensis[3]			
Mountain big sagebrush-mesic east with conifers	*A. t.* ssp. *vaseyana/Pseudoroegneria spicata*[3] *A. t.* ssp. *vaseyana/Festuca idahoensis*[3] *A. t.* ssp. *vaseyana-Symphoricarpos oreophilus/Pseudoroegneria spicata*[3] *A. t.* ssp. *vaseyana-Symphoricarpos oreophilus/Festuca idahoensis*[3]	Conifers (Douglas-fir and Rocky Mountain juniper) are associated with the mountain big sagebrush PVT. Decreased occurrence of fire has resulted in more continuous conifer overstory and conifer expansion into sagebrush sites.	**Slightly altered:** These sites have abundant herbaceous species associated with sagebrush PVT and moderate levels of conifers. **Severely altered:** Herbaceous sagebrush associated species are severely reduced. Recovery is rapid if a seed source is present (Bunting and others 1987, Ferguson 2001).	Fire occurrence has decreased in these communities as a result of fire suppression and removal of fine fuels by grazing. The lack of fire has allowed for more continuous forest canopy development and expansion into sagebrush communities (Arno and Gruell 1983).
Mountain big sagebrush-mesic west	*Artemisia tridentata* ssp. *vaseyana/Festuca idahoensis*[1,3,6] *A. t.* ssp. *vaseyana/Pseudoroegneria spicata*[3] *A. t.* ssp. *vaseyana-Symphoricarpos oreophilus/Pseudoroegneria spicata*[3] *A. t.* ssp. *vaseyana-Symphoricarpos oreophilus/Festuca idahoensis*[3] *A. t.* ssp. *vaseyana-Symphoricarpos oreophilus/Bromus carinatus*[6]	This PVT is common on mid to upper mountain slopes. Often it is found in the Wyoming big sagebrush-warm PVT at elevations >3,300 ft.	**Slightly altered:** These sites are characterized by the occurrence of invasive species (knapweed species) and increased sagebrush density. Native perennials are still maintained in the community. **Severely altered:** Invasive species dominate the understory with native perennial species lacking.	Fire occurrence has decreased in these communities as a result of fire suppression and removal of fine fuels by grazing. The lack of fire has allowed for more continuous forest canopy development and expansion into sagebrush communities (Arno and Gruell 1983).
Mountain big sagebrush-mesic west with juniper	*Artemisia tridentata* ssp. *vaseyana/Festuca idahoensis*[3] *A. t.* ssp. *vaseyana-Symphoricarpos oreophilus/Festuca idahoensis*[3]	Juniper woodland is the late seral stage of this PVT occurring at the sagebrush steppe and pinyon-juniper woodland interface.	**Slightly altered:** small juniper in mostly intact sagebrush steppe community characterizes these sites. **Severely altered:** These sites have converted to woodlands. Herbaceous cover is reduced and seed sources are lost increasing recovery time following fire (Bunting and others 1999). This	Reductions in fire frequency are the primary cause of woodland conversion, however, grazing, and climatic change are also important factors. Following fire suppression and removal of fine fuels following

Potential vegetation type (PVT)	Prior habitat type classification	Site characteristics	Stages of community alteration	Fire characteristics
			conversion increase soil erosion on many sites (Davenport and others 1998).	grazing, juniper encroaches (Burkhardt and Tisdale 1976, Miller and Rose 1999, Miller and Wigand 1994). Fire is infrequent in woodland stand due to a lack of fine fuels.

Source: Bunting and others 2002.
[1] Daubenmire (1970) eastern Washington.
[2] Mueggler and Stewart (1980) western Montana.
[3] Hironaka and others (1983) southern Idaho.
[4] Yensen and Smith (1984) southwestern Idaho.
[5] Zamora and Tueller (1973) northern Nevada.
[6] Johnson (1987) northeastern Oregon.

Appendix G—Native vegetation alliances documented through the National Vegetation Classification for Nevada.

Vegetation Alliance	Dominant vegetation
Artemisia arbuscula ssp. *arbuscula* shrub herbaceous	*Artemisia arbuscula ssp. arbuscula / Achnatherum thurberianum* *Artemisia arbuscula ssp. arbuscula / Festuca idahoensis* *Artemisia arbuscula ssp. arbuscula / Poa secunda* *Artemisia arbuscula ssp. arbuscula / Pseudoroegneria spicata*
Artemisia arbuscula ssp. *longicaulis* shrubland	*Artemisia arbuscula ssp. longicaulis - Grayia spinosa [Provisional]* *Artemisia arbuscula ssp. longicaulis / Bromus tectorum [Provisional]* *Artemisia arbuscula ssp. longicaulis / Elymus elymoides [Provisional]*
Artemisia arbuscula ssp. *longiloba* shrub herbaceous	*Artemisia arbuscula ssp. longiloba / Festuca idahoensis* *Artemisia arbuscula ssp. longiloba / Poa secunda*
Artemisia arbuscula ssp. *longiloba* shrubland	*Artemisia arbuscula ssp. Longiloba*
Artemisia cana (ssp. *bolanderi*, ssp. *viscidula*) shrub herbaceous	*Artemisia cana (ssp. bolanderi, ssp. viscidula) - Artemisia tridentata ssp. vaseyana / Poa cusickii [Provisional]* *Artemisia cana (ssp. bolanderi, ssp. viscidula) / Poa fendleriana ssp. fendleriana* *Artemisia cana ssp. bolanderi / Muhlenbergia richardsonis*
Artemisia cana (ssp. *bolanderi*, ssp. *viscidula*) shrubland	*Artemisia cana (ssp. bolanderi, ssp. viscidula) / Leymus cinereus* *Artemisia cana (ssp. bolanderi, ssp. viscidula) / Poa secunda* *Artemisia cana ssp. bolanderi / Eleocharis palustris [Provisional]*
Artemisia nova shrubland	*Artemisia nova - Ericameria nana* *Artemisia nova / Achnatherum hymenoides* *Artemisia nova / Elymus elymoides* *Artemisia nova / Hesperostipa comata* *Artemisia nova / Poa secunda* *Artemisia nova / Pseudoroegneria spicata* *Artemisia nova*
Artemisia pygmaea shrubland	*Artemisia pygmaea / Elymus elymoides – Achnatherum hymenoides*
Artemisia tridentata (ssp. tridentata, ssp. xericensis) shrub herbaceous	*Artemisia tridentata (ssp. tridentata, ssp. xericensis) / Pseudoroegneria spicata*
Artemisia tridentata (ssp. tridentata, ssp. xericensis) shrubland	*Artemisia tridentata ssp. tridentata - Grayia spinosa* *Artemisia tridentata ssp. tridentata / Distichlis spicata* *Artemisia tridentata ssp. tridentata / Festuca idahoensis* *Artemisia tridentata ssp. tridentata / Hesperostipa comata* *Artemisia tridentata ssp. tridentata / Leymus cinereus* *Artemisia tridentata ssp. tridentata / Pascopyrum smithii - (Elymus lanceolatus)* *Artemisia tridentata ssp. tridentata / Poa secunda*
Artemisia tridentata shrub herbaceous	*Artemisia tridentata / Festuca idahoensis* *Artemisia tridentata / Leymus cinereus*
Artemisia tridentata shrubland	*Artemisia tridentata / Achnatherum hymenoides* *Artemisia tridentata / Achnatherum lettermanii*

Vegetation Alliance	Dominant vegetation
	Artemisia tridentata / Chrysothamnus viscidiflorus / Poa secunda
	Artemisia tridentata / Elymus elymoides
	Artemisia tridentata / Ericameria nauseosa
	Artemisia tridentata / Pleuraphis jamesii
	Artemisia tridentata / Symphoricarpos longiflorus
	Artemisia tridentata Shrubland
	Artemisia tridentata Upperzone Community
Artemisia tridentata ssp. vaseyana shrub herbaceous	*Artemisia tridentata ssp. vaseyana / Carex geyeri*
	Artemisia tridentata ssp. vaseyana / Festuca idahoensis
Artemisia tridentata ssp. vaseyana shrubland	*Artemisia tridentata ssp. vaseyana - Purshia tridentata / Pseudoroegneria spicata*
	Artemisia tridentata ssp. vaseyana - Symphoricarpos oreophilus / Bromus carinatus
	Artemisia tridentata ssp. vaseyana - Symphoricarpos oreophilus / Elymus trachycaulus ssp. trachycaulus
	Artemisia tridentata ssp. vaseyana - Symphoricarpos oreophilus / Hesperostipa comata
	Artemisia tridentata ssp. vaseyana - Symphoricarpos oreophilus / Poa secunda
	Artemisia tridentata ssp. vaseyana - Symphoricarpos oreophilus / Pseudoroegneria spicata
	Artemisia tridentata ssp. vaseyana / Achnatherum occidentale
	Artemisia tridentata ssp. vaseyana / Bromus carinatus
	Artemisia tridentata ssp. vaseyana / Festuca idahoensis - Bromus carinatus
	Artemisia tridentata ssp. vaseyana / Hesperostipa comata
	Artemisia tridentata ssp. vaseyana / Leucopoa kingii - Koeleria macrantha
	Artemisia tridentata ssp. vaseyana / Leucopoa kingii
	Artemisia tridentata ssp. vaseyana / Leymus cinereus
	Artemisia tridentata ssp. vaseyana / Poa secunda
	Artemisia tridentata ssp. vaseyana / Pseudoroegneria spicata - Poa fendleriana
	Artemisia tridentata ssp. vaseyana / Pseudoroegneria spicata
Artemisia tridentata ssp. wyomingensis shrub herbaceous	*Artemisia tridentata ssp. wyomingensis / Pseudoroegneria spicata*
Artemisia tridentata ssp. wyomingensis shrubland	*Artemisia tridentata ssp. wyomingensis / Achnatherum thurberianum*
	Artemisia tridentata ssp. wyomingensis / Balsamorhiza sagittata
	Artemisia tridentata ssp. wyomingensis / Elymus elymoides
	Artemisia tridentata ssp. wyomingensis / Poa secunda
	Artemisia tridentata ssp. wyomingensis / Pseudoroegneria spicata

Appendix H—Draft fire regime condition class reference conditions for cool mountain big sagebrush communities without trees.

11/4/03 DRAFT
Fire Regime Condition Class (FRCC) Interagency Handbook
Reference Conditions
Modeler: Doug Havlina Date: 8/15/03 PNVG Code: CSAG1

Potential Natural Vegetation Group: Sagebrush-Cool (Mountain Big Sagebrush) Without Trees.

Geographic Area: Pacific Northwest, Columbia Plateau, Northern Rockies, Central Rockies, Great Basin.

Description: PNVG commonly found at the upper elevations of the big sagebrush zone, sites are usually montane valleys, mountain slopes, and subalpine meadows. Mountain big sagebrush often occurs at ecotones with conifer forests and meadow habitats between 2500' and 9800' elevation. Soils are characterized as moderately well drained, typically having summer moisture from snowmelt or other sources. Common associates include quaking aspen, ponderosa pine, Douglas-fir, subalpine fir, and whitebark pine.

Fire Regime Description: Fire Regimes III and II; primarily short-interval (e.g., 20-40 yr) mixed severity- and stand replacement fires.

Vegetation Type and Structure

Class	Percent of Landscape	Description
A: post replacement	20	Post-fire community of mountain forbs, grasses, and sprouting shrubs
B: mid-development closed	25	Mid-seral, dense (>15%) canopy cover sagebrush stands with understory of mountain forbs and grasses
C: mid- open	40	Mid-seral, open (<15%) sagebrush community with perennial grasses and forbs in interspaces
D: late- open	10	Late-seral, open (<15%) sagebrush community with mixed shrub/herbaceous community
E: late- closed	5	Late-seral, closed (>15%) sagebrush community, noticeable dead component, with mixed shrub/herbaceous community
Total	100	

Fire Frequency and Severity

Fire Frequency-Severity	Modeled Probability	Pct, All Fires	Description
Replacement Fire	.024	40	Crown fire in stages A, B, D and E
Non-Replacement Fire	.036	60	Mosaic fire in stages B, C, and D
All Fire Frequency*	.06	100	

*Sum of replacement fire and non-replacement fire probabilities.

Appendix I—Canopy cover, basal area and density of western juniper in mountain big sagebrush and low sagebrush communities[1].

Species	Maturity class	Number of sites	Canopy cover (percent)	Basal area (m^2/ha)	Density (number/ha) Adults (>0.5 m ht.)	Juveniles (<0.5 m ht.)
Mountain big sagebrush	Closed	6	22 (18-28)	5.2 (3.1-9.8)	296 (217-496)	580 (118-1226)
	Intermediate	8	6 (5-10)	1.8 (0.5-4.7)	95 (50-165)	815 (335-1423)
	Dispersed	2	2 (1-3)	0.4 (0.2-0.6)	52 (31-70)	188 (96-280)
Low sagebrush	Closed	3	15 (12-20)	3.5 (1.8-5.4)	158 (74-247)	99 (20-198)
	Intermediate	3	6 (4.5-6.7)	1.8 (0.9-3.2)	104 (77-153)	375 (167-790)

Source: Miller and Rose 1995.

[1] Range of values follows in parentheses ().

Appendix J—Standing crop at perennial grass peak production and percent live vegetation between burned and unburned sagebrush steppe-grass ecosystems near Burns, Oregon.

Year	Perennial bunchgrasses Live	Perennial bunchgrasses Dead	Sandberg's bluegrass Live	Sandberg's bluegrass Dead	Perennial forb Live	Perennial forb Dead	Annual forb Live	Annual forb Dead	Total biomass Live	Total biomass Dead	Total biomass Total	Percent of live vegetation	Date of peak perennial grass production
	lb/acre											%	
1998													
Unburned	428[1]	418	---	---	150[2]	0	---	---	579	418	997	58	June 8
Burn	320	24	---	---	206	0	---	---	526	24	551	95	June 8
1999													
Unburned	360	392	62	106	52[2]	8	---	---	475	520	995	48	June 15
Burn	627	339	35	95	113	29	---	---	777	463	1240	63	June 15
2000													
Unburned	183	467	1	73	46	6	1	3	230	549	779	30	June13
Burn	354	443	8	57	99	23	5	13	465	537	1003	47	June 1
2001													
Unburned	272	466	92	57	56	12	28	0.1	450	530	979	46	May 9
Burn	350	414	44	78	82	13	13	7	488	512	1000	49	May 22
2002													
Unburned	191	430	42	48	56	37	8	4	293	507	800	37	May 23
Burn	240	407	25	26	76	44	11	9	351	484	836	42	May 23
2003													
Unburned	202	367	47	63	78	3	34	10	359	443	802	45	June 2
Burn	155	276	1	73	49	2	5	35	208	386	594	35	June 16

[1] Grass production in 1998 includes both perennial bunchgrasses and Sandberg's bluegrass.
[2] Forb in 1998 and 1999 includes both perennial and annual forbs.

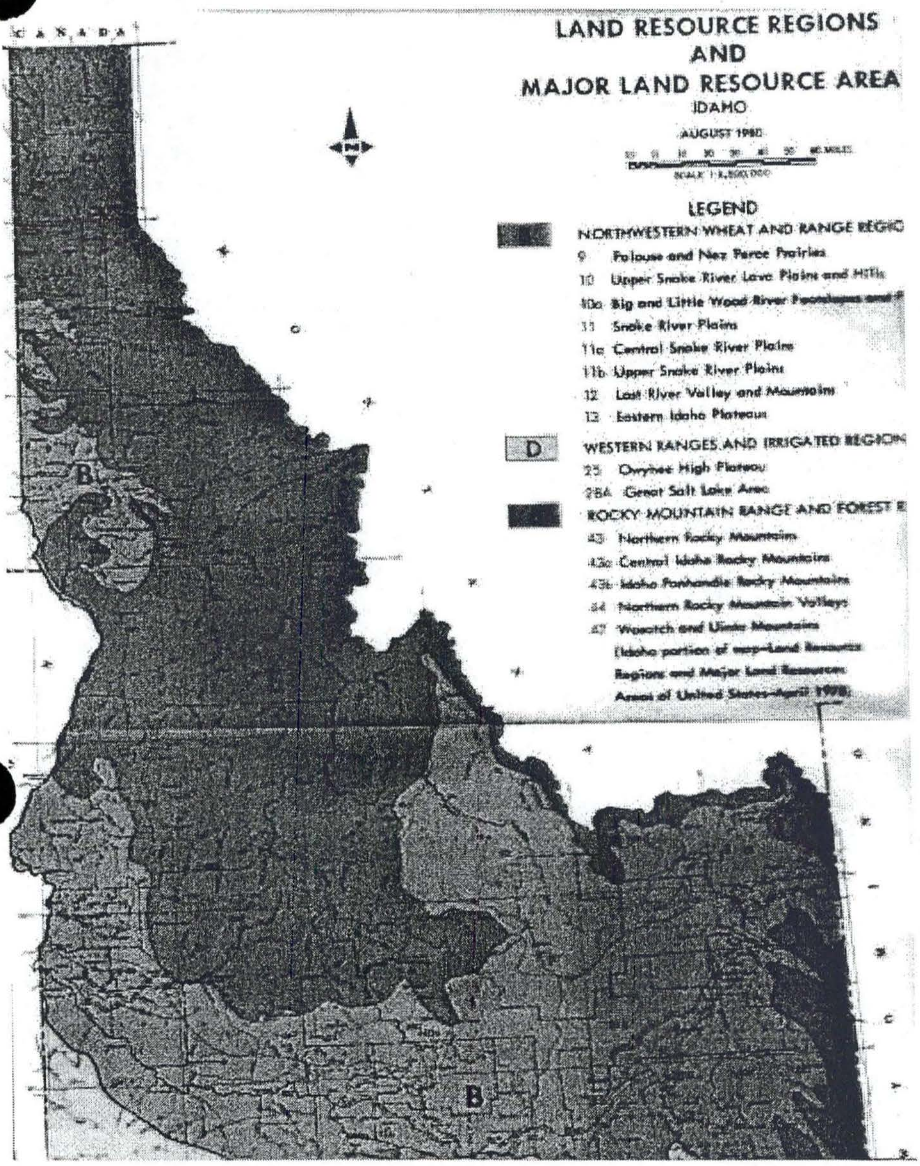
Source: Bates 2004.

Appendix K. Classification used by the BRRC (Biological Resource Research Center) for developing land cover types of Nevada (http://www.brrc.unr.edu/).

GAP vegetation classification	BRRC aggregation
Ash	Ash
Aspen2	Montane forest
Aspen3	Montane forest
Engelmann spruce 2	Montane forest
Engelmann spruce 3	Montane forest
Great Basin subalpine pine 1	Montane parkland
Great Basin subalpine pine 2	Montane forest
Juniper 1	Pinon-juniper
Juniper 2	Pinon-juniper
Mojave bristlecone 1	Montane parkland
Mojave bristlecone 2	Montane forest
Mojave bristlecone 3	Montane forest
Mountain mahogany 1	Montane parkland
Mountain mahogany 2	Montane forest
Mountain mahogany 3	Montane forest
Pinyon 1	Pinon-juniper
Pinyon 2	Pinon-juniper
Pinyon-juniper 1	Pinon-juniper
Pinyon-juniper 2	Pinon-juniper
Ponderosa pine 1/mountain brush	Montane parkland
Ponderosa pine2	Montane forest
Sierra lodgepole 1	Montane parkland
Sierra lodgepole 2	Montane forest
Sierra lodgepole 3	Montane forest
Sierra red fir 2	Montane forest
Sierra red fir 3	Montane forest
Sierra whitebark 1	Montane parkland
Sierra whitebark 2	Montane forest
Sierra white fir 3	Montane forest
Sierra yellow pine 1	Montane parkland
Sierra yellow pine 2	Montane forest
Sierra yellow pine 3	Montane forest
Sierra yellow pine/mountain shrub	Montane parkland
Subalpine fir 2	Montane forest
Subalpine fir 3	Montane forest
White fir 1	Montane parkland
White fir 2	Montane forest

White fir 3	Montane forest
Bitterbrush	Sagebrush scrub
Blackbrush	Mojave
Creosote-bursage	Mojave
Greasewood	Shadscale
Hopsage	Shadscale
Mesquite	Mesquite
Mojave mixed scrub	Mojave
Mountain sagebrush	Montane shrub
Mountain shrub	Montane shrub
Sagebrush	Sagebrush scrub
Sagebrush/perennial grass	Sagebrush steppe
Salt desert scrub	Shadscale
Sierra mountain shrub	Montane shrub
Alpine	Alpine
Dry meadow	Grassland
Grassland	Grassland
Wet meadow	Wetland
Agriculture	Agriculture
Barren	Barren
Lowland riparian	Riparian
Mountain riparian	Riparian
Playa	Barren
Sand dunes	Barren
Snow	Alpine
Urban	Urban
Water	Water
Wetland	Wetland

Appendix L. Major Land Resource Areas for Idaho.



Appendix M . List of Idaho range sites where *Artemisia* was a cover type for MRLA 10 (Upper Snake River Lava Plains and Hills.

010AY001ID STONY CLAY 12-16 ARARL/FEID
010AY002ID CLAYEY 12-16 ARTR4/PSSP6
010AY003ID LOAMY 12-16 ARTRT/FEID
010AY004ID LOAMY 12-16 ARTRV/FEID
010AY005ID GRAVELLY LOAM 12-16 ARTRV/FEID
010AY006ID CLAYEY 11-14 ARARL/PSSP6
010AY007ID SHALLOW STONY LOAM 8-16 ARAR8/PSSP6
010AY008ID N SLOPE LOAMY 16-20 ARTRV/FEID
010AY009ID S SLOPE GRAVELLY 12-16 ARTRV/PSSP6
010AY010ID N SLOPE FRACTURED 16-22 ARTRV/FEID
010AY011ID SHALLOW LOAM 16-20 ARAR8/FEID

010AY012ID N SLOPE CLAYEY 16-20 ARAR8/FEID
010AY013ID N SLOPE LOAMY 18-24 ARTRV-SYOR2/FEID
010AY014ID STEEP SLOPE 16-22 ARTRV-SYOR2/PSSP6
010AY015ID S SLOPE LOAMY 16-20 ARTRV/FEID
010AY017ID CLAYEY 12-16 ARARL/FEID
010AY018ID S SLOPE CLAYEY 12-16 ARAR8/PSSP6
010AY019ID LOAMY 12-16 ARTRV/PSSP6
010AY020ID MIXED SHRUB 12-16 ARTRV/POSE
010AY021ID S SLOPE FRACTURED 12-16 ARTRV/PSSP6
010AY022ID LOAMY 12-16 ARTRT/PSSP6
010AY023ID LOAMY 12-16 ARTR4/FEID
010AY024ID STONY WINSWEPT 8-16 ARNO4/POSE
010AY025ID LOAMY SLOPE 11-13 ARTRW8/PSSP6
010AY026ID LOAMY 11-13 ARTRW8/PSSP6
010AY029ID CLAYPAN 12-16 ARAR8/PSSP6
010AY030ID S SLOPE CHANNERY 11-13 ARTRX/PSSP6
010AY031ID BOULDERY LOAM 12-16 ARTRV/FEID
010AY032ID BOULDERY 11-13 ARTRX/PSSP6
010AY033ID LOAMY 11-13 ARTRX/PSSP6
010AY034ID CLAYPAN 11-13 ARTR4/PSSP6-STTH2
010AY035ID LOAMY BASIN 11-13 ARTR4/PSSP6
010AY036ID N SLOPE STONY 12-16 ARTRX/PSSP6
010AY037ID SHRUBBY STONY N 12-16 ARTRV/FEID
010AY038ID STONY CLAYEY 8-16 ARAR8/PSSP6

010XY002ID VERY SHALLOW 12-20 ARRI2/POSE
010XY003ID LOAMY 16-22 PUTR2/FEID
010XY004ID S SLOPE LOAMY 16-22 ARTRX/PSSP6
010XY005ID N SLOPE LOAMY 16-22 ARTRV/FEID
010XY006ID CHURNING CLAY 8-16 ARTRX/PSSP6
010XY007ID LOAMY 12-16 ARTRX/PSSP6
010XY008ID GRANITIC 12-16 ARTRX/PSSP6
010XY009ID STONY LOAM 12-16 ARTRT/PSSP6
010XY010ID N SLOPE LOAMY 12-16 ARTRX/PSSP6
010XY011ID S SLOPE STONY 12-16 ARTRT/PSSP6
010XY013ID N SLOPE GRANITIC 16-22 ARTRV/FEID
010XY014ID N SLOPE GRANITIC 12-16 ARTRX/FEID
010XY015ID SHALLOW STONY LOAM 12-16 ARAR8/PSSP6
010XY016ID SHALLOW S STONY 12-16 ARTRX/PSSP6
010XY017ID SHALLOW STONY 16-22 ARAR8/FEID
010XY019ID S SLOPE LOAMY 12-16 ARTRX/PSSP6
010XY021ID STONY LOAM 16-22 ARTRT/PSSP6
010XY025ID SHALLOW STONY LOAM 12-16 ARTRX/PSSP6
010XY026ID SHALLOW STONY LOAM 16-22 ARTRX/FEID

Appendix N. Idaho range site description (to be added).

Appendix O. Oregon ecological sites of the Central Rocky and Blue Mountain Pumice Zone (Major Resource Land Area (MRLA) B10A).
Oregon ecological site descriptions available from NRCS web site (http://www.or.nrcs.usda.gov/).

Site Number	Name	HCPC Plant Association	Soil Temp	Production Favorable	Production Normal	Production Unfavorable	NASIS Plants
010XA001OR	DROUGHTY LOAM 8-10 PZ	PSSP6/ARTRT-PUTR2/JUOC	Mesic	1100	900	700	PSSP6 (60) FEID (5) ARTRT (10) POSE (10)
010XA002OR	PUMICE HILLS 8-10 PZ	HECO26-ORHY/ARTRT-PUTR2/JUOC	Mesic	1000	800	600	HECO26 (50) JUOC (5) ARTRT (5) PUTR2 (5) ACTH7 (5) POSE (5) ACHY (5) FEID (5)
010XA003OR	DROUGHTY JUNIPER FAN 8-10 PZ	PSSP6-ACTH7-FEID/ARTRT/JUOC	Mesic	1000	800	600	HECO26 (40) PSSP6 (15) ACHY (10) ARTRT (10) JUOC (5)
010XA007OR	SOUTH 10-12 PZ	PSSP6/ARTRT/JUOC	Mesic	900	700	500	PSSP6 (60) JUOC (5) PUTR2 (5) ACTH7 (5) POSE (5) FEID (5) ARTRT (10)
010XA009OR	PUMICE FLAT 10-12 PZ	FEID-HECO26/ARTRT/JUOC	Mesic/Frigid	1100	900	700	FEID (30) ACOC3 (5) JUOC (5) ELMA7 (5) ACTH7 (5) ACHY (5) ARTRV (10) PUTR2 (10) HECO26 (20)
010XA014OR	CINDERY HILLS 10-12 PZ	PSSP6/ARTRW/JUOC	Mesic	600	500	300	PSSP6 (55) JUOC (5) ACTH7 (5) POSE (10) ARTRW (15)
010XA018OR	LOAMY 10-12 PZ	PSSP6/PUTR2/JUOC	Mesic	1100	900	700	PSSP6 (40) POSE (5) ARTR (10) PUTR2 (10) FEID (25)
010XA019OR	DROUGHTY 8-12 PZ	PSSP6-ACTH7-POSE/ARTRT-PUTR2/JUOC	Mesic	800	600	400	ERMI4 (5) ACTH7 (5) ARTRT (10) POSE (10) PSSP6 (35)
010XA021OR	SHALLOW PUMICE HILLS 10-12 PZ	FEID/ARTRV/JUOC	Frigid	1000	800	600	FEID (60) KOPY (5) ACTH7 (5) JUOC (10) ARTRV (10)
010XA022OR	LAVA BLISTERS 8-10 PZ	PSSP6-ACTH7-POSE/ARTRV/JUOC	Mesic	800	600	400	PSSP6 (45) JUOC (5) ACHY (5) FEID (5) ARTRV (10) ACTH7 (10) POSE (10)
010XA023OR	LAVA BLISTERS 10-12 PZ	PSSP6-FEID/ARTRV-PUTR2/JUOC	Mesic	900	700	500	JUOC (5) ARTRV (5) ACTH7 (5) POSE (5) PUTR2 (10) FEID (10) PSSP6 (35)
010XA024OR	PUMICE NORTH 8-10 PZ	FEID-PSSP6-HECO26/ARTRV/JUOC	Mesic	1100	900	700	FEID (45) PSSP6 (20) ARTRV (10) ARTRT (5) JUOC (5)
010XA025OR	SHALLOW NORTH 10-12 PZ	PSSP6-FEID-POSE/ARTRV/JUOC	Mesic	1000	800	600	FEID (30) ERMI4 (5) POSE (5) JUOC (10) ARTRV (10) PSSP6 (30)
010XA026OR	PUMICE NORTH 10-12 PZ	FEID-PSSP6/ARTRV/JUOC	Frigid	1100	900	700	JUOC (5) POSE (5) ARTRV (10) PSSP6 (20) FEID (40)
010XA027OR	PUMICE FLAT 8-10 PZ	HECO26-FEID-ACOC3/ARTRV/JUOC	Frigid	1000	800	600	HECO26 (40) ACOC3 (5) JUOC (5) ELMA7 (5) ARTRT (5) ACTH7 (5) ACHY (5) FEID (10)
010XA040OR	VERY SHALLOW PUMICE HILLS 8-11 PZ	FEID-ACOCO-PSSP6-ACTH7/ARTRV/JUOC	Frigid	500	350	200	FEID (20) ACOCO (10) PSSP6 (10) ACTH7 (5) ARTRV (15) JUOC (10)
010XA083OR	SANDY NORTH 10-12 PZ	FEID-PSSP6/PUTR2-ARTRV/JUOC	Mesic	1400	1200	900	FEID (30) JUOC (5) KOPY (5) ARTRV (5) ACTH7 (50) POSE (10) PSSP6 (10) PUTR2 (15)

Appendix P. Oregon ecological sites "Droughty Loam 8-10 inch precipitation zone (MLRA B10A).
Oregon ecological site descriptions available from NRCS web site (http://www.or.nrcs.usda.gov/).

Site Name	DROUGHTY LOAM 8-10 PZ						
Site Number	010XA001OR						
Plant Association	PSSP6/ARTRT-PUTR2/JUOC						
Normal Lbs./Ac.	900						
Range of composition and weight of species in HCPC with normal production:				% Comp. by Wt.		Lbs./Acre	
Common Name	Scientific Name	Symbol	Group	Low	High	Low	High
Grasses & Grass-like Plants				87%	75%	621	819
bluebunch wheatgrass	Pseudoroegneria spicata	PSSP6	1	55	65	495	585
Sandberg bluegrass	Poa secunda	POSE	3	10	15	90	135
Idaho fescue	Festuca idahoensis	FEID	2	1	5	9	45
Thurber's needlegrass	Achnatherum thurberianum	ACTH7	2	1	2	9	18
Indian ricegrass	Achnatherum hymenoides	ACHY	2	1	2	9	18
basin wildrye	Leymus cinereus	LECI4	2	1	2	9	18
						0	0
						0	0
						0	0
						0	0
						0	0
						0	0
Forbs				1%	6%	9	63
Other Perennial Forbs	N/A	PPFF	9	1	7	9	63
buckwheat (Eriog.)	Eriogonum	ERIOG				0	0
snow buckwheat	Eriogonum niveum	ERNI2				0	0
fleabane	Erigeron	ERIGE2				0	0
tapertip hawksbeard	Crepis acuminata	CRAC2				0	0
fernleaf biscuitroot	Lomatium dissectum	LODI				0	0
mariposa lily	Calochortus	CALOC				0	0
Palouse milkvetch	Astragalus arrectus	ASAR7				0	0
spreading phlox	Phlox diffusa	PHDI3				0	0
common yarrow	Achillea millefolium	ACMI2				0	0
arrowleaf balsamroot	Balsamorhiza sagittata	BASA3				0	0
yellow salsify	Tragopogon dubius	TRDU				0	0
lupine	Lupinus	LUPIN				0	0
pussytoes	Antennaria	ANTEN				0	0
agoseris	Agoseris	AGOSE				0	0
						0	0
						0	0
						0	0
						0	0
						0	0
Shrubs				9%	16%	63	171
basin big sagebrush	Artemisia tridentata ssp. tridentata	ARTRT	11	5	15	45	135
antelope bitterbrush	Purshia tridentata	PUTR2	12	1	2	9	18
Other Shrubs	N/A	SSSS	15	1	2	9	18
shrubby buckwheat	Eriogonum microthecum	ERMI4				0	0
granite prickly phlox	Leptodactylon pungens	LEPU				0	0
gray rabbitbrush	Ericameria nauseosa	ERNA10				0	0
spineless horsebrush	Tetradymia canescens	TECA2				0	0
green rabbitbrush	Chrysothamnus viscidiflorus	CHVI8				0	0
						0	0
						0	0
Trees				3%	4%	18	45
western juniper	Juniperus occidentalis	JUOC	16	2	5	18	45
						0	0
						0	0
Totals				100%	100%	711	1098

Appendix P (continued). Oregon ecological sites "Droughty Loam 8-10 inch precipitation zone (MRLA B10A). **Oregon ecological site descriptions available from NRCS web site (http://www.or.nrcs.usda.gov/).**

Site Name	DROUGHTY LOAM 8-10 PZ
Site Number	010XA001OR

Initial Stocking Rates by General Seral Condition (AUMs/Acre/Year with normal production) Use with caution - only when field determination is not practical or possible	Class	Poor	Fair	Good	Excellent
	Low	0.03	0.08	0.14	0.20
	High	0.04	0.13	0.22	0.30

Rangeland Health Indicator [wt]	Potential for this Site
1. Number and extent of rills [1.0]	None, Slight sheet & rill erosion hazard
2. Presence of water flow patterns [1.0]	None
3. Number and height of erosional pedestals or terracettes [1.0]	None
4. Bare ground (rock, litter, lichen, moss, plant canopy are not bare ground) [1.0]	5-10%
5. Number of gullies and erosion associated with gullies [1.0]	None
6. Extent of wind scoured, blowouts and/or depositional areas [1.0]	None to some, Severe wind erosion hazard
7. Amount of litter movement (size and distance of travel) [1.0]	Fine - limited movement
8. Soil surface resistance to erosion (average stability values) [1.0]	Moderately resistant to erosion: aggregate stability = 3-5
9. Soil surface structure and Soil Organic Matter (SOM) content [1.0]	Moderately deep to shallow, well drained loams and sandy loams: low OM (1-3%)
10. Effect of plant community composition and spatial distribution on infiltration & runoff [1.0]	Significant ground cover (55-65%) and level to gently rolling slopes (2-15%) limit rainfall impact and overland flow
11. Presence and thickness of compaction layer [1.0]	None
12. Functional / structural groups (listed in order of descending dominance) [1.0]	Bluebunch wheatgrass > Sandberg bluegrass > basin big sagebrush > forbs > Idaho fescue = western juniper > other grasses = antelope bitterbrush = other shrubs
13. Amount of plant mortality and decadence [1.0]	Normal decadence and mortality expected
14. Average percent litter cover and depth (inches) [1.0]	8-12% (<0.5") in most areas
15. Expected annual production (total above-ground) [1.0]	Favorable: 1100, Normal: 900, Unfavorable: 700 lbs/acre/year at high RSI (HCPC)
16. Potential invasive (including noxious) species (native and non-native) [1.0]	Perennial brush species will increase with deterioration of plant community. Western Juniper readily increases on the site. Cheatgrass and Medusahead invade sites that have lost deep rooted perennial grass functional groups
17. Perennial plant reproductive capability [1.0]	All species should be capable of reproducing annually

Appendix Q. Natural vegetation of Oregon (modified from Kagan and others 2004).

Community Type	Ecoregion	References with plot data
Artemisia arbuscula - Purshia tridentata / Pseudoroegneria spicata - Festuca idahoensis	EM, BR, EC	unpublished
Artemisia arbuscula - Purshia tridentata / Stipa :hurberiana	EC	Dealy 1971:67.
Artemtsia arbuscula / Festuca idahoensis	EC, BR	Dealy 1971:80; Volland 1976: 25; Hopkins 1979a: 17; Hopkins 1979b: 10; Day & Wright 1985: 4 (ID).
Artemisia arbuscula / Poa secunda	BM, BR, EC	Dealy 1971 : 85, 89; Hopkins 1979a: 10, 15; Christy & Cornelius 1980: plot 8; Day & Wright 1985:3(10).
Artemisia arbuscula / Pseudoroegneria spicata	BM, BR, EC	Hall 1973: 14.
Artemisia cana - Artemisia tridentata ssp. vaseyana / Poa fendleriana	BR	unpublished
* Artemisia cana / Deschampsia cespitosa	BM	Crowe & Clausnitzer 1997: 159.
* Artemisia cana / Eleocharis palustris	BM, BR BR	Titus 1995a; Titus et al. 1998.
Artemisia cana / Leymus cinereus		unpublished
* Artemisia cana / Muhlenbergia richardsonis	IBR	Dealy 1971: 93; Manning & Padgett 1991: 222 (NV); Moseley 1998: 46 (ID).
* Artemisia cana / Poa fendleriana	BM, BR, EC	Christy & Cornelius 1980: plot 9; Padgett 1981: 58; Kovalchik 1987: 65; Titus et al. 1998.
Artemisia cana / Poa secunda	BR BM	Titus 1995a; Moseley 1998. 46 (ID); Titus et al. 1998.
* Artemisia ludoviciana		Moseley 1998: 47 (ID); Titus et al. 1998.
Artemisia nova / Poa secunda	BR	unpublished
Artemisia nova / Pseudoroegneria spicata	BR	unpublished
* Artemisia papposa	BM	Moseley 1998: 47 (ID)
Artemisia rigida / Poa secunda	BM, CB, BR	Daubenmire 1970 (WA); Hall 1973: 13, 47; Ganskopp 1979: 46, 100; Copeland 1980: 58; Johnson & Simon 1987: 138; Easterly & Salstrom 1998: 32 (WA).
Artemisia rigida / Pseudoroegneria spicata	BM, BR	unpublished
Artemisia spinescens / Elymus elymoides	BR	unpublished
Artemisia tridentata ssp. tridentata / Festuca idahoensis	CB, BM, BR	unpublished
Artemisia tridentata ssp. tridentata / Leymus cinereus	CB, BM, BR	Moseley 1998: 29 (ID).
Artemisia tridentata ssp. tridentata / Poa secunda -Pseudoroegneria spicata	CB	Easterly & Salstrom 1998: 14 (WA).
Artemtsia tridentata ssp. tridentata / Hesperostipa comata	CB, BM. BR	Daubenmire 1970 (WA); Hironaka et al. 1983: 29 (ID); Easterly & Salstrom 1998: 23 (WA).
Artemisia tridentata ssp. vaseyana - Ephedra viridis	BR	unpublished
Artemisia tridentata ssp. vaseyana - Purshia tridentata / Festuca idahoensis	EC	Dealy 1971:69.
Artemtsia tridentata ssp. vaseyana / Achnatherum occidentalis	BR,EC	Dealy 1971: 74; Volland 1976: 27; Day & Wright 1985: 3 (ID); Johnson & Clausnitzer 1992: 147

* Listed as a wetland type.

Source: Kagan, James S., John A. Christy, Michael P. Murray, and Jonathan A. Titus. January 2004. Classification of native vegetation of Oregon. Oregon Natural Heritage Information Center (http://oregonstate.edu/ornhic/publications.html, June 2005).
Ecoreg identifies the ecoregion in which the plant association is known to occur in the state of Oregon. Oregon's ten ecoregions ecoregion is identified by a two-letter code; BM = Blue Mountains, BR = Northern Basin and Range, CB = Columbia Basin, CR = Coast Range, EC = East slope of Cascade Range, KM = Klamath Mountains, WV = Willamette Valley, WC = West slope and crest of Cascade Range.

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Appendix R . Average leaf and flower stalk height of bluebunch wheatgrass *(Pseudoroegneria spicata)* and arrowleaf balsamroot (*Balsamorhiza saggittata)* at the end of the growing season, 1932-47.

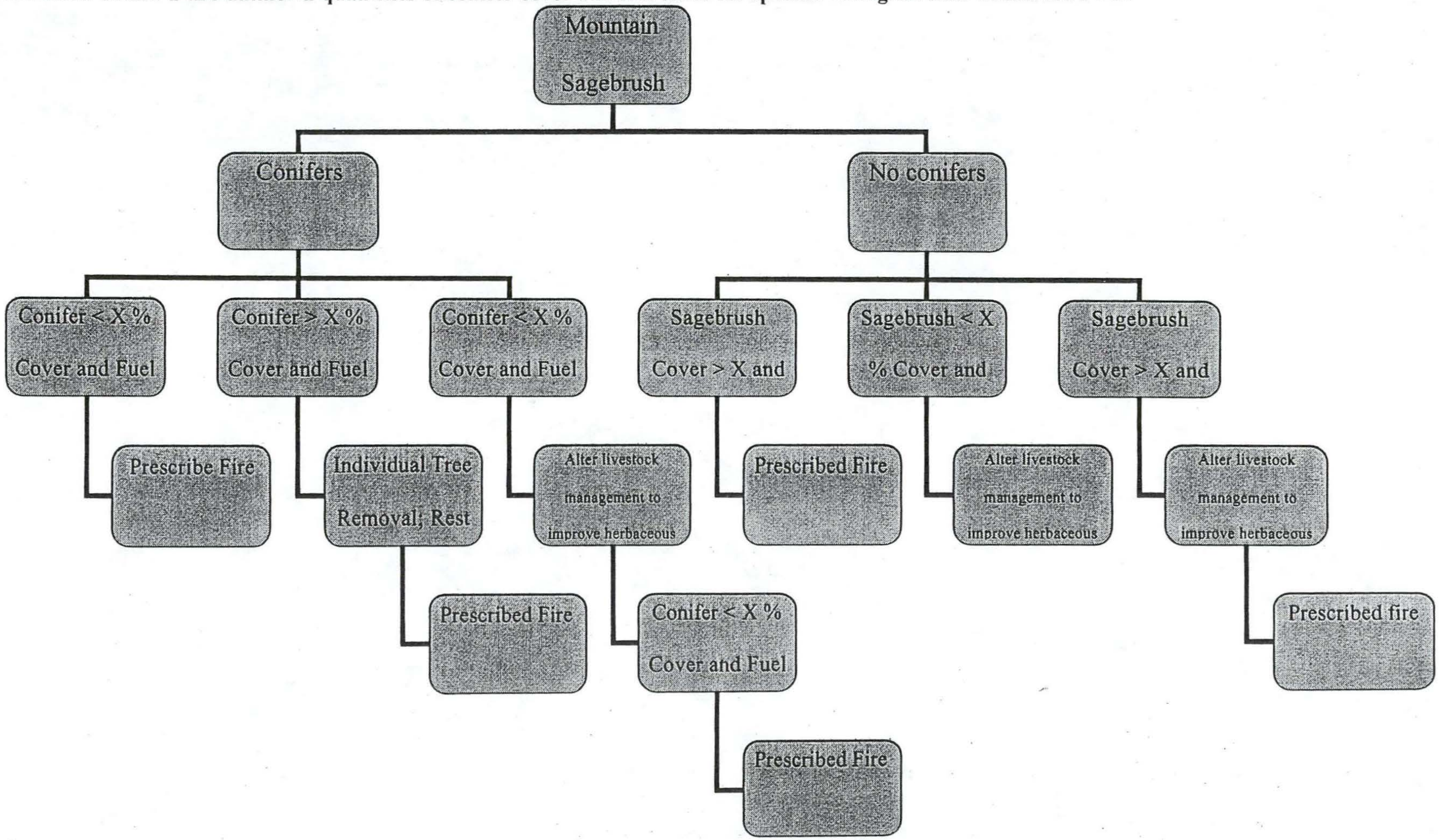
YEAR	Bluebunch wheatgrass		Arrowleaf balsamroot	
	Leaves	Flower stalks	Leaves	Flower stalks
1932	17.6	37.3	28.6	42. 8
1933	21.0	37.0	24. 9	----
1934	11. 4	18.0	14.8	24.2
1935	19. 2	39. 3	24. 4	44. 6
1936	12.2	----	20. 8	34.0
1937	13. 8	34.0	18.4	41. 8
1938	18. 6	34. 9	23.6	30.3
1939	16.0	33.3	23.6	----
1940	18. 6	38.0	26. 4	25. 8
1941	13.4	43.6	23.9	35.9
1942	15.4	24. 6	25.3	23. 6
1943	12.5	----	20. 1	35.6
1944	16.3	45.5	24.5	32.5
1945	19. 7	43. 2	28.9	35.0
1946	19.2	42. 6	23. 3	27.0
1947	18. 2	30.0	24.2	43.5

Source: Blaisdell, J.P. 1958. Seasonal development of yield of native plants on the upper Snake River plains and their relation to certain climatic factors. Technical Bulletin No. 1190. U.S. Department of Agriculture. Washington, D.D. 68 p.

Appendix S. Population status of some wild species of economic concern found in the Great Basin and dependent on sagebrush habitats (from BLM, Great Basin Restoration Initiative. Nov. 1999, Boise, ID.).

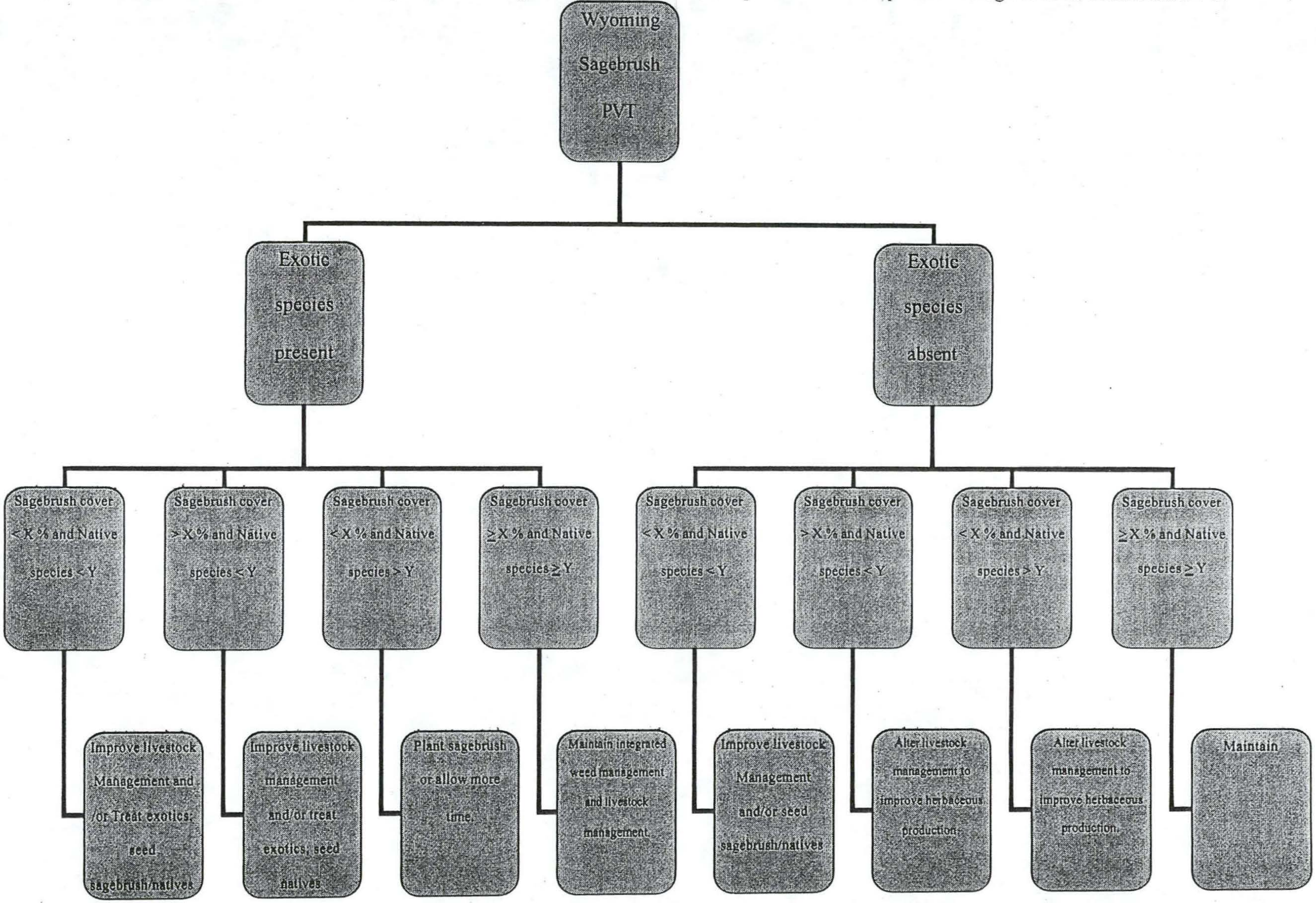
Species	**Current Status**	**Projected Status**
Mule deer	Declining	Declining
Prognhorn antelope	Declining	Declining
Rocky Mountain Bighorn Sheep	Stable	Declining
California Bighorn Sheep	Stable	Declining
Columbian sharp-tailed grouse	Declining	Declining
Sage grouse	Declining	Declining
Gray partridge	Stable	Declining
California quail	Stable	Declining
Mountain quail	Declining	Declining
Chukar partridge	Stable	Declining

Appendix T. A simplified flow diagram of restoration treatments considered for hypothetical Mountain Big Sagebrush PVT wi thout exotic plant invasion. X and Y are unknown quantities of conifer cover and fuel loads for specific ecological sites within the PVT.



In this flow diagram, exotic plants are not present. Restoration activities are associated with removing conifer invasion, increasing fuel loads or herbaceous production through better livestock management and/or removal of conifers. Where exotic plants become introduced or are expected to increase to levels impacting the site, the flow diagram becomes much more complicated with numerous treatments to be considered in an integrated weed management plan.

Appendix U. A simplified flow diagram of restoration treatments considered for hypothetical Wyoming Big Sagebrush PVT with and without exotic plant invasion. X and Y are unknown quantities of sagebrush cover and native plant cover for specific ecological sites within the PVT.



In this flow diagram, exotic plants are present but prescribed fire is not recommended. If fire, burns through the area then treatments are associated with conditions of too low sagebrush cover but treatments may not be needed if across the landscape this succession stage is uncommon and exotic plant invasion is not a risk. Where exotic plant invasion is a risk treatments would be based on the exotic or group of exotics and level of natives. Where exotic plants become introduced or are expected to increase to levels impacting the site, the flow diagram becomes much more complicated with numerous treatments to be considered in an integrated weed management plan.

Phase 3. Provide additional materials not included in CRS

A list of items currently not found in CRS is available. References include:

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